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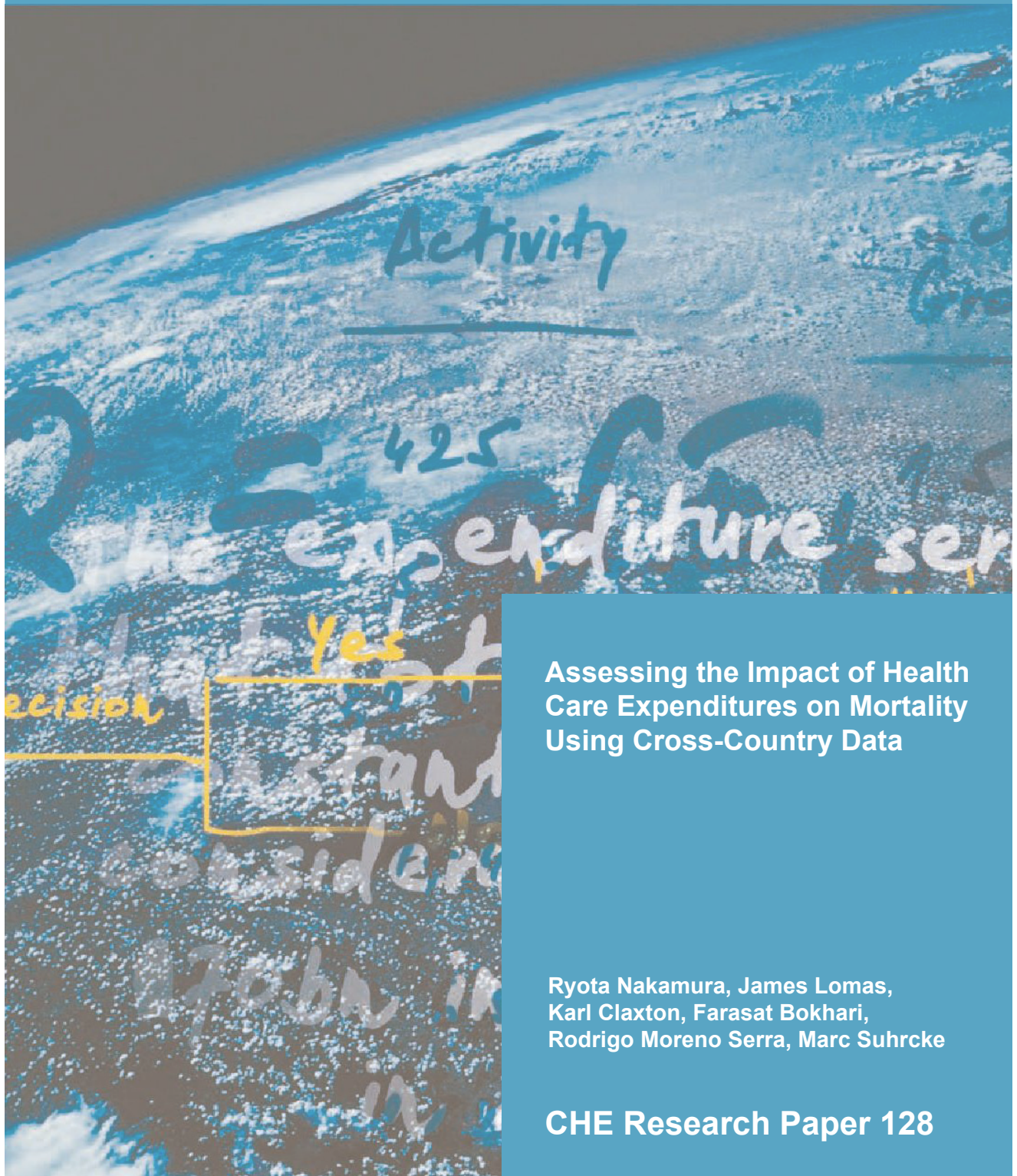
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Assessing the Impact of Health  
Care Expenditures on Mortality  
Using Cross-Country Data

Ryota Nakamura, James Lomas,  
Karl Claxton, Farasat Bokhari,  
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CHE Research Paper 128



# Assessing the impact of health care expenditures on mortality using cross-country data

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**Abstract**

A significant body of literature has examined the impact of public health expenditure on mortality, using a global cross-section or panel of country-level data. However, while a number of studies do confirm such a relationship, the magnitude of the impact varies considerably between studies, and several studies show statistically insignificant effects. In this paper we re-examine the literature that identifies this effect using cross-country data. Our analysis builds on the two instrumental variables (IV) approaches embodied by key publications in the field – Bokhari et al. (2007) and Moreno-Serra and Smith (2015). Using exactly the same data and econometric specifications as the published studies, we start by successfully replicating their findings. However, further analyses using updated data and ‘streamlined’ econometric specifications, plus statistical data imputation and extensive robustness checks, reveal highly sensitive results. In particular, the relevance of the IVs is seriously compromised in the updated data, leading to imprecise estimations of the relationship. While our results should not be taken to imply that there is no true mortality-reducing impact of public health care expenditures on mortality, the findings do call for further methodological work, for instance in terms of identifying more suitable IVs or by applying other estimation strategies, in an effort to derive more robust estimates of the marginal productivity of public health care funding.

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## 1. Introduction

The question of whether, and if so, by how much, public health care expenditures impact on mortality outcomes has occupied and challenged researchers for some decades (Gravelle and Backhouse, 1987). While it is hard to imagine that – if the true relationship were in fact measurable – public health care expenditures would not ‘buy’ mortality reductions, all else equal, in reality there may well be ‘weak links in the chain’ from spending to outcomes (Filmer et al., 2000). Out of the significant body of empirical studies that have attempted to estimate the relationship, some previous studies confirm the expected sign and significance of the relationship, yet the magnitude of the impact varies considerably between studies, and several studies show statistically insignificant effects. For instance, an influential study by Filmer and Pritchett (1999), using global cross-country panel data, found at best a small impact of public health care expenditures on under-five-mortality rates, with a 1% increase in spending leading to a – statistically insignificant – reduction in under-5 mortality by 0.19%, and in infant mortality rates by 0.078%. By contrast, Bokhari et al. (2007) – using a cross-section of data from the year 2000 and an instrumental variable strategy that broadly follows Filmer and Pritchett (1999) – find that a 1% increase in public health care expenditure significantly (both in statistical and economic terms) reduces under-5 mortality by between 0.25 and 0.42%, and maternal mortality by 0.42 to 0.52%. Those findings have been reinforced very recently by Moreno-Serra and Smith (2015), using again a large cross-country panel analysis with a novel estimation strategy that allows them to explicitly model the reverse causality from mortality onto spending. Some studies have also pointed to potential nuances in the relationship, e.g. in the sense that public spending matters most for the health of poor people in lower income countries (Bidani and Ravallion, 1997), or that mortality is only reduced in response to public spending when the overall quality of governance in a country exceeds a certain threshold level (Wagstaff and Claeson, 2004; Rajkumar and Swaroop, 2008). However, while a number of papers do claim to have established a causal relationship between expenditure and mortality outcomes, the magnitude of the impact varies considerably between studies.

In light of these ambiguities, and in order to reflect potential changes in the relationship between public expenditure on health and mortality over time, we revisit the literature that identifies this effect using cross-country data.

Re-estimating this relationship is important for several reasons. To the extent that we are able to derive a robust empirical relationship, this would allow us to capture the marginal productivity of the publicly funded health care system, i.e. the opportunity costs of public health care spending, which in turn would be a crucial element to derive more useful cost-effectiveness threshold estimates than have hitherto been promoted, for instance in the widely used form of the 1-3 times per capita GDP rule-of-thumb. This ‘rule’ was initially proposed by the WHO Commission on Macroeconomics and Health (WHO 2001), and has subsequently been taken up by the World Health Organization (WHO 2015). From there its use has spread massively, not least for lack of obvious other alternatives. However, the limitations – and potential harms – of this approach have increasingly been recognised (Revill et al., 2014; Newall et al., 2014; Marseille et al. 2015). Recent UK-focused research has shown how cost-effectiveness thresholds can empirically be estimated, starting from rigorous empirical estimates of the impact of spending on health outcomes (Claxton et al., 2015). Cross-country based analysis of the kind presented in the present paper has the potential to inform empirically derived thresholds in countries world-wide, including low- and middle-income countries (LMICs) where the prioritization of health care resources to maximise population health gains is particularly warranted (Ochalek et al., 2015).

In this paper we employ an empirical strategy rooted in the literature that has estimated the mortality effects of public health care expenditure using instrumental variable strategies – by far the

most popular strategy to tackle endogeneity in this literature. While we cannot fully reflect the specific approach taken in every single paper in this literature (see Table A10 for an overview of a select set of studies), we first examine the robustness of two exemplary studies – by Bokhari et al., (2007) and Moreno-Serra and Smith (2015), henceforth referred to as BGG and MSS, respectively – to new data, whilst preserving the papers’ original model specifications. In the second, major step of the analysis we then abstract slightly from the two exact specifications to construct panel data models using instrumental variables and covariates taken from our review of the existing literature. In doing so we still preserve the ‘spirit’ of the two approaches, by applying both a traditional approach to instrumentation (broadly following Bokhari et al (2007)) along with an application of Bruckner (2013), which is the approach followed by Moreno-Serra and Smith (2015). (See Methods section for more details on the two approaches). As part of the second step we also undertake a battery of robustness checks, not least to accommodate some other estimation approaches used in the literature (e.g. dynamic panel analysis). Taken together we argue that following the empirical approaches proposed in these two studies – first literally and then more generally – allows us to capture the currently most promising approaches that have been used in this literature.

We argue that Bokhari et al. (2007), apart from having become a highly cited paper in this literature, broadly represents the IV approach adopted in several such papers, starting from Filmer & Pritchett (1999) and Wagstaff and Claeson (2004). Moreno-Serra and Smith (2015), by contrast, offer a different (though also IV based) approach that, for the first time in this literature, allows for an explicit assessment of the extent of reverse causality, running from mortality to health spending.

By following the above broad strategy we comprehensively re-examine the robustness of the empirical relationship between public health care spending and mortality outcomes using cross-country data, as it was presented in the main approaches used by the previous literature. Across the two replicated studies, we find that in the majority of replication scenarios the effect of public health care expenditure on mortality is negative, although qualitative conclusions based on statistical significance vary and the magnitude of the impact is sensitive to revisions and updates in the data used. New results from our ‘streamlined’ model, using a traditional IV approach, are unreliable on account of the chosen instrument (per capita military expenditure of neighbouring countries) being found to not be statistically relevant. For another ‘streamlined’ model, using a novel identification strategy based on Bruckner (2013) and Moreno-Serra and Smith (2015), at least in some cases the estimated effects are broadly consistent with the previous literature, finding that public spending reduced mortality, although at generally lower effect magnitudes and with mixed degrees of statistical significance. Our very mixed findings should not be taken to imply that the conclusions from the previous studies are necessarily invalid, and conclusions need to be seen in the light of the considerable methodological challenges (relating to data and econometric techniques) faced by this strand of research.

## 2. Methods

Our basic model is specified as follows. We use country-level panel data including low-, middle- and high-income countries. Our primary focus is to estimate the causal impact of public health expenditure on mortality outcomes. To this end, we consider the following simple linear model:

$$\text{Eq. (1): } MO_{jt} = \beta_j + \beta_1 EX_{jt} + \mathbf{X}'_{jt}\boldsymbol{\beta} + \varepsilon_{jt}$$

MO is mortality and EX is public healthcare expenditure in country  $j$  at time  $t$ . The vector  $\mathbf{X}$  represents covariates. Our main goal is to estimate  $\beta_1$ , which represents the expenditure elasticity when the natural logarithm of MO and EX are used in the regression model i.e. the effect of a 1% increase in expenditure on the % change in mortality. While health care expenditure may reduce mortality, policymakers may increase health expenditure in response to an increase in mortality – i.e. the idea of reverse causality. Also, mortality and health expenditure may be correlated with a third variable (which is often not observed in the data), which gives rise to omitted variable bias on the estimated coefficients. Given these concerns in this observational setting, we need an exogenous variation of expenditure EX to identify the causal impact of EX on MO (which is represented by the coefficient  $\beta_1$ ).

Following both BGG and MSS, we use an instrumental variable approach. BGG and MSS use distinct IV approaches which differ in their econometric specification and also in their strategy in identifying the causal impact of expenditure. Employing more than one approach allows us to assess the robustness and sensitivity of the estimated impacts to different econometric approaches using the same data. Hence we start our analyses by replicating the analyses of BGG and MSS respectively, using their original data as well as our updated data. In order to assess the extent to which their conclusions may be driven by their specific features of the models (e.g. choice of variables and data years), we also construct a streamlined version of econometric model with our own set of variables (based on a review of the literature), and augment the two distinct approaches to estimate the impact of health expenditure on mortality outcomes.

### 2.1 BGG model

BGG use a more traditional IV approach that may be seen as broadly representative for a range of existing studies published before. However, this particular study uses cross sectional data from 2000 (as opposed to panel data from multiple years), and also employs a structurally motivated model that investigates the impact of health expenditure as well as GDP per capita on mortality.

The main outcome variables in the BGG model are log of under-5 mortality and log of maternal mortality. There are four key independent variables which are treated as endogenous. The endogenous variables include GDP per capita, public health care expenditure and two interaction terms involving public health expenditure: 1) public health expenditure and deviation in donor funding on basic health from historical mean; and 2) public health care expenditure and the quantity of paved roads per unit area in the country (as a proxy of economic development). The model includes the following covariates: log of proportion of non-literate (proxy of education); log of quantity of paved roads per unit area; log of donor funding; and log of proportion of population with access to improved sanitation.

BGG use a number of instrumental variables in their first stage regression with the four endogenous variables. The IVs include: 1) log of neighbours' military expenditure per capita, and its interaction with a) deviation in donor funding on basic health from historical mean and b) the quantity of paved roads per unit area; 2) indicators of quality of policies and institutions (based on World Bank's

annual assessment of countries), and again its interaction with deviation in donor funding from historical mean and paved road rate; and finally 3) the log of the consumption-investment ratio.

## 2.2 MSS model

MSS use a more novel IV approach inspired by Bruckner (2013), which explicitly takes into account the reverse causality from mortality to health expenditure. In this approach, as the first step, we estimate the reverse causality – the impact of mortality on health care expenditure:

$$\text{Eq. (2): } EX_{jt} = \gamma_j + \gamma_1 MO_{jt} + \mathbf{X}'_{jt}\boldsymbol{\gamma} + \epsilon_j$$

Note that we use the same set of covariates (vector  $\mathbf{X}$ ) in this reverse causality model. Once we estimate  $\gamma_1$  by a panel fixed effect instrumental variable regression, we calculate the following residual:

$$\text{Eq. (3): } EX_{jt}^* = EX_{jt} - \widehat{\gamma_1} MO_{jt}$$

Assuming the instruments used in Eq. (2) are valid and relevant, this residual is now orthogonal to the variation of mortality. In the second step, we use this residual as an IV for health expenditure in Eq. (1) to estimate the impact of health expenditure on mortality.

The main outcome variables in the MSS study are: under-5 mortality, adult female mortality, and adult male mortality. MSS specify four endogenous indicators of health expenditure: a) public health care expenditure; b) private out-of-pocket health care expenditure; c) expenditure from private voluntary health insurance; and d) immunization coverage. We therefore estimate Eq. (2) and calculate the residual in Eq. (3) for each endogenous variable separately, but estimate the impact of these variables in one main regression Eq. (1) with four endogenous variables. Since the panel data are clustered at country level, the estimation of the standard errors takes this data structure into account through the use of cluster-robust standard errors.

In the MSS model the covariates include: GDP per capita, primary education enrolment rate, proportion of population under 14, and proportion of population over 65. Note that, in contrast with BGG, in the MSS analysis GDP per capita is treated as an exogenous control variable. In the streamlined model below we follow this simplification of the model because our main purpose is specifically to estimate the impact of health expenditure on mortality, which we pursue using a reduced form specification.

## 2.3 Streamlined model

As described above, BGG and MSS have specific features in terms of data, selection of variables, and strategy to estimate causal impacts. For instance, BGG use cross-sectional data whereas MSS use panel data<sup>1</sup>; they use different set of health expenditure variables (some of which are not our primary interest) and also different sets of covariates. These particular features might have led to

<sup>1</sup> On the whole there is good reason to expect that *all else equal*, using panel data allows for more credible inference than cross-sectional data as the former allows the researcher to control for unobserved time invariant factors at country level directly via a fixed effects estimator. This can be important if such a source of unobserved heterogeneity is both correlated with health spending and mortality outcomes as it would then reduce the need for finding appropriate IVs for the health spending variable (assuming of course that there is no other source of endogeneity). Alternatively, if the omitted time invariant variable is not correlated with health spending, one can use random effects models instead of fixed effects for a gain in efficiency. Generally, both types of panel estimators are an improvement over simple cross-sections. The problem, and hence the trade-off in panel vs cross-section data comes from not being able to obtain reliable time series on all variables of interest. This can happen when some of the variables of interest have been provided by data dissemination agencies by interpolating for missing values.

different magnitudes of the main estimates or even their conclusions. In order to still follow the ‘spirits’ of the two approaches represented by these studies without strictly adhering to their highly specific models, we construct our own model specifications (which we refer to as ‘streamlined’ models) as described below.

### **2.3.1 Data structure and panel data analysis for streamlined model**

We use country level panel data from 1995 to 2011. This means that in applying a traditional IV approach we complement the above-described, cross-sectional BGG analysis by incorporating further, more recent data points, and by allowing for country-level fixed effects in the model and estimate a within-country impact of health expenditure. This will additionally take into account any unobserved, time invariant country-level heterogeneity. Furthermore, the country level fixed effect is also likely to account for some of the (unobserved) heterogeneity from factors that vary only slowly over time (and particularly in shorter time series), such as cultural factors and institutional quality. MSS’s original study uses data from 1995 to 2008. We therefore include more recent years (up to 2011) in our Bruckner IV approach analysis (Bruckner, 2013). Descriptive statistics of the streamlined model are given in Table 3.

### **2.3.2 Outcome variables**

We follow MSS in choosing our outcome variables. We use: under-5 mortality, adult female mortality, and adult male mortality. However, while MSS use under-5 mortality estimated by the Institute of Health Metrics and Evaluation, we use estimates produced by the United Nations (as in BGG). This is because more data are available in the UN mortality data (up to 2011) than in the IHME data (up to 2010).

### **2.3.3 Health care expenditure**

While BGG and MSS specified a number of endogenous variables, in our streamlined model we focus only on public health care expenditure following a reduced form approach. In particular, in line with MSS, in our main model we treat GDP per capita as an exogenous control variable to keep the model parsimonious.<sup>2</sup> Moreover, although BGG include two interaction terms involving the rate of paved road and the amount of donor funding on basic health, we drop these interaction terms from our streamlined model because some of the data are not available, and also because these factors are not of primary interest to us.<sup>3</sup> Similarly, we exclude three of MSS’s key explanatory variables, i.e. out-of-pocket expenditure, private insurance expenditure and immunization coverage, for the same reason.<sup>4</sup>

<sup>2</sup> Appendix Table A9 presents the model where per capita GDP is treated as an endogenous variable. Following BGG, we used the consumption-investment ratio as the instrument for per capita GDP. The estimated effect of per capita GDP is negative and in some cases the effect is statistically significant, i.e. higher national income reduces mortality. The estimated impact of public health expenditure in this model is largely similar to the estimates presented in the main paper. Also, using BGG’s original data and following their specification, we estimated the model with per capita GDP treated as exogenous variable. We find that the impacts of public expenditure on the mortality outcomes are largely maintained (the impact is -0.390 (SE=0.128) for under-5 mortality; and it is -0.607 (SE=0.190) for maternal mortality). These additional results imply that assuming per capita GDP as exogenous should not substantially bias the estimation of the impact of public healthcare expenditure on mortality outcomes in our data.

<sup>3</sup> Using BGG’s original data, we estimated the BGG’s model while excluding the interaction terms and also assuming per capita GDP to be exogenous. The impacts of public expenditure on mortality outcomes are qualitatively maintained (the impact is -0.419 (SE=0.096) for under-5 mortality; and it is -0.565 (SE=0.163) for maternal mortality).

<sup>4</sup> Dropping private expenditure might lead to misspecification of the model and therefore bias the estimated impact of public healthcare expenditure. However, as shown in Table 4, dropping the private expenditure from the original MSS specification does not affect the impact of public expenditure to a substantive degree. Also, in Appendix Table B1, we estimate the impact of *total* healthcare expenditure (which includes both public and private expenditure) on mortality, and find that the results are similar to the principal estimation results presented in the main text (Table 6). This might be because public healthcare expenditure accounts for a majority of healthcare resources in many (though by no means all) countries and thus the potential bias from omitting private expenditure may be negligible.

### 2.3.4 Instrumental variables

Based on our review of the existing literature, we use instrumental variables, which have been shown to be relevant in the previous literature, including BGG and MSS. However, since we estimate within-country impact by using fixed effect models, our instrumental variables should vary over time. Therefore we cannot use time-invariant IVs (i.e. certain dimensions of governance quality and their interactions) in the streamlined model.

As explained in the sections 2.1 and 2.2, in the traditional IV analysis we need instruments for public health care expenditure, whereas the Bruckner IV analysis requires instruments for mortality. In the traditional IV approach, we use neighbours' military expenditure (in % of GDP) and neighbours' public health expenditure (in % of GDP) as instrumental variables (Filmer and Pritchett, 1999; Wagstaff and Claeson, 2004).<sup>5 6</sup>

Our instruments in the Bruckner IV approach include per capita emission of CO<sub>2</sub> and number of deaths by conflict per 100,000 people, following MSS. As a sensitivity check we also use WHO's data on external causes of death as additional IVs predicting exogenous variations in mortality.<sup>7</sup> Test statistics for the relevance of the IVs are presented and discussed in the Results section.

### 2.3.5 Covariates

Previous studies (including but not limited to BGG and MSS) use a variety of covariates, and there appears to be no common set of covariates that has been applied in all studies. In this study we use the following principle-based selection of covariates. We conduct a literature review of the related, cross-country type studies. We identified and reviewed 11 studies and recorded covariates from each study (Afridi and Ventelou, 2013; Akinci et al. 2014; Anyanwu and Erhijakpor, 2009; Bokhari et al. 2007; Farag et al. 2013; Filmer and Pritchett, 1999; Gani, 2009; Hu and Mendoza 2013; Moreno-Serra and Smith, 2015; Rajkumar and Swaroop, 2008; and Wagstaff and Claeson, 2004).<sup>8</sup> From the full set of candidates we obtain a shortlist of covariates in the following way: first, we exclude variables if we decide they can be outcomes of health expenditure (e.g. number of hospital beds), as including those variables would cause selection bias in the regression (Angrist and Pischke, 2009). Second, we follow Hauck et al. (2015) in our selection of further covariates:

- 1) We drop a variable if, in the currently available data, more than 60% of observations between 1995 and 2011 are missing across years and countries;
- 2) In order to avoid multi-collinearity among covariates, we calculate the pair-wise correlation between the de-meanned candidate variables and drop one of the variables, if the correlation coefficient is above 0.6.<sup>9</sup>

<sup>5</sup> In preliminary analyses we also employed a 'just identified' model with one instrumental variable, where we used per capita military expenditure of neighbouring countries for the single endogenous variable (i.e. public health care expenditure) in the main model. We found this single instrument was too weak in terms of the first stage F statistics (F is less than 1 in most cases).

<sup>6</sup> A rationale for the IV is that if neighbouring countries spend more on military equipment and services, the domestic government would increase or decrease military expenditure to maintain the military balance, which would affect the level of healthcare expenditure per capita. Note that this IV has been widely used in the previous literature - see Anyanwu and Erhijakpor (2009), Bokhari et al. (2007), Filmer and Pritchett (1999), and Wagstaff and Claeson (2004).

<sup>7</sup> External causes of death include: transport accidents, smoke and fire, poisoning, falls, drowning, and assault, which largely randomly occur across the population.

<sup>8</sup> These studies were collected using a 'snowballing' strategy, in which we started by looking at the reference list of BGG and MSS studies for relevant studies, then once we found a related study (initially judged by title, and then by full text), we included the study in our review and also checked the reference list of the study for further references. We iterated this process for several times, thus converging towards the set of studies included in our review.

<sup>9</sup> De-meanned variables (i.e. we calculate the mean of a given variable for each country and then subtract the country's mean over the observed time period) are used because we use fixed effect models, in which de-meanned variables are analysed in the regression.

Our final set of covariates is as follows: GDP per capita, primary education enrolment rate, proportion of population under 14, proportion of population over 65, rate of paved road, access to improved sanitation, urbanisation, and two measures of efficiency of governance (government efficiency and control of corruption). See Table 3 for more detail.

Finally, in the streamlined model we use log-scale variables (which is consistent with BGG but not MSS). All analyses are conducted using Stata 13 MP.



### 3. Data

For the most part the main data sources we make use of are those used in the two papers we are being guided by here – BGG and MSS – both of which use data sources that have been commonly employed in the relevant literature. For the original replication of the published results the authors of the original articles generously allowed us full access to the original data (and codes) that were used for the published results of those papers. When updating the data to include the most recently available ones, we also used, wherever accessible, the sources indicated in the two papers. It should be noted that for most of the variables even the older data are regularly revised in the publicly available data sources, and it is not always possible to obtain older versions of the database.

The majority of our data comes from three widely used sources: the World Bank's World Development Indicators (WDI), the World Health Organization's Global Health Observatory, and the Institute of Health Metrics and Evaluation's 'Global Health Data Exchange'. The sources, definitions, and downloaded data of all the variables we used in our empirical analysis study are given in Appendix Table A1.<sup>10</sup>

Tables 1 and 2 give the descriptive statistics of each of the composed datasets we use in our analysis: First, for the original and updated data analysis of the BGG paper (Table 1), and second for the MSS paper (Table 2). In these tables, there are some notable discrepancies between original data and updated data, which could be attributable to data updates by the data providers, or to differences in the exact metric used for a given variable.<sup>11</sup> In Table 1, the original data consist of 127 countries whereas the updated data consist of 238 countries. Similarly, in Table 2, the original data consist of 158 countries whereas the updated data consist of 250 countries. Appendix Table C1 and C2 present the descriptive statistics for the subset of updated data using the same set of countries as in the original data. The discrepancies between the original and updated data become smaller. In the results section we examine the impacts of using different versions of GDP data on the regression results (see Appendix Tables A2-A5 for detailed results).

#### 3.1 Data imputation

Although we use the most up-to-date data that is currently available in the public domain, significant numbers of missing values do remain. The sample size in different studies (BGG, MSS and others) varies significantly (from around 100 to 150 countries) as a result, depending on the selection of variables and versions of the data source used in their analyses.

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<sup>10</sup> Note that data on mortality are from the World Bank's WDI database (i.e. for adult female mortality rate, adult male mortality rate, maternal mortality rate, and under-5 mortality rate). The under-5 mortality data available in the WDI database are based on United Nations' estimates. IHME have produced alternative estimate of under-5 mortality, and it does not appear obvious which one of the two is closer to the truth (Alkema and You, 2012).

<sup>11</sup> For instance, the updated data has GDP per capita based on purchasing power parity in 2011 constant dollars, but MSS used GDP per capita based on purchasing power parity in 2005 constant dollars, and BGG used GDP per capita in 2000 international dollars (also based on purchasing parity). It should be noted that Table 1 and 2 compare outcomes from different set of countries.

**Table 1: Descriptive statistics of BGG data (original data and updated data)**

	Original data (2000)			Updated data (2000)*					
	Mean	SD	N	Mean	SD	N	# missing	max N	Missing rate
Under 5 mortality	73.49	68.91	127	57.67	58.17	192	46	238	19.33%
Maternal mortality	345.39	425.07	127	264.23	361.86	183	55	238	23.11%
GDP per capita†	6962.60	7987.95	127	14396.85	18467.87	185	53	238	22.27%
Public health expenditure‡	311.21	509.70	127	542.53	866.97	186	52	238	21.85%
Neighbours' military expenditure per capita	161.04	183.22	127	271.48	383.53	222	16	238	6.72%
World Bank CPI on Social inclusion and equity	3.63	0.76	127	.	.	.	.	.	100.00%
World Bank CPI on Economic management	3.96	1.05	127	.	.	.	.	.	100.00%
Investment-GDP ratio	14.87	8.71	127	22.79	9.92	189	49	238	20.59%
Donor funding on basic health per capita	2.96	6.35	127	.	.	.	.	.	100.00%
Nonliterate rate	21.22	22.15	127	21.32	21.01	101	195	296	65.88%
Paved road rate	31.14	66.63	127	49.37	32.86	169	114	283	40.28%
Sanitation rate	73.98	26.67	127	68.51	31.15	198	40	238	16.81%

Notes:

\* In this column the analysis include as many countries as possible (max available number of countries is 238) from the updated data sources.

† In the original data, GDP per capita using international dollars as of 2000 is used. In the updated data, GDP per capita using constant US dollars 2011 (PPP adjusted) is used.

‡ In the original data, government health expenditure per capita (international dollars as of 2000) is used. In the updated data, government health expenditure per capita in 2005 constant dollars is used.

**Table 2: Descriptive statistics of MSS data (original data and updated data)**

	Original data (1995-2008)			Updated data (1995-2008)*					
	Mean	SD	N (153 countries)	Mean	SD	N (250 countries)	# missing	max N	Missing rate
Under 5 mortality	45.68	48.87	1397	52.26	52.93	2618	713	3331	21.40%
Adult female mortality	155.85	114.87	1225	173.97	129.77	2696	635	3331	19.06%
Adult male mortality	226.39	116.92	1225	242.39	123.48	2696	635	3331	19.06%
Public health expenditure (1/100)†	5.99	8.43	1397	5.93	10.19	2602	729	3331	21.89%
Privately pooled health expenditure (1/100)	0.59	2.10	1397	2.77	14.27	2602	729	3331	21.89%
Out-of-pocket health expenditure (1/100)	1.88	2.04	1397	0.58	1.93	2233	1098	3331	32.96%
Immunization coverage (1/10)	8.61	1.42	1397	8.43	1.65	2688	643	3331	19.30%
GDP per capita (1/100)‡	121.15	131.67	1397	148.27	183.98	2578	753	3331	22.61%
Primary education enrollment rate (1/10)	8.61	1.59	1397	8.84	1.54	1477	1854	3331	55.66%
Proportion of population under 14 (1/10)	3.07	1.05	1397	3.19	1.05	2716	615	3331	18.46%
Proportion of population over 65 (1/10)	0.75	0.52	1397	0.70	0.47	2716	615	3331	18.46%
CO2 emission per capita	5.16	6.51	1397	4.79	6.74	2728	603	3331	18.10%
Death by conflict	1.45	25.76	1397	1.11	17.01	3331	0	3331	0.00%

Notes: \* In this column the analysis include as many countries as possible (max available number of countries is 229) from the updated data sources.

† In the original data, government health expenditure per capita (international dollars as of 2005) is used. In the updated data, government health expenditure per capita in 2005 constant dollars is used.

‡ In the original data, GDP per capita using international dollars as of 2005 is used. In the updated data, GDP per capita using constant US dollars 2011 (PPP adjusted) is used.

The variable 'Death by conflict' does not have any missing values. The original SIPRI data (see Appendix Table A1) lists the cases of conflicts and the number of deaths where they observed. Following Morreno-Serra and Smith (2015), we assume that there were not conflicts (and therefore no deaths) if the original data do not list any information for a given country.

**Table 3: Descriptive statistics of the streamline model data (1995-2011)**

	Mean	SD	N (253 countries)	# missing	max N	Missing rate
<i>Mortality outcomes</i>						
Under 5 mortality (UN estimate)	51.70	53.78	3264	781	4,045	19.31%
Adult female mortality	171.16	128.47	3239	806	4,045	19.93%
Adult male mortality	238.45	122.25	3239	806	4,045	19.93%
<i>Health expenditure</i>						
Total health expenditure	1085.90	4025.17	3163	882	4,045	21.80%
Public health expenditure	631.03	1206.37	3163	882	4,045	21.80%
<i>Covariates</i>						
GDP per capita	15234.72	18652.36	3147	898	4,045	22.20%
Sanitation rate	69.69	30.77	3299	746	4,045	18.44%
Primary education enrollment rate	89.06	14.66	1849	2196	4,045	54.29%
Proportion of population under 14	31.38	10.62	3299	746	4,045	18.44%
Proportion of population over 65	7.10	4.77	3299	746	4,045	18.44%
Paved road rate	53.93	33.04	1621	2424	4,045	59.93%
Urban rate	55.46	24.47	3587	458	4,045	11.32%
Efficiency of governance	-0.01	1.00	2629	1416	4,045	35.01%
Control of corruption	-0.01	1.00	2635	1410	4,045	34.86%
<i>Instrumental variables</i>						
CO2 emission per capita	4.76	6.63	3383	662	4,045	16.37%
Death by conflict (per 100,000)	0.99	15.49	4045	0	4,045	0.00%
Neighbours' military expenditure per capita	296.13	442.08	3723	322	4,045	7.96%
Neighbours' health expenditure per capita	589.29	951.79	3723	322	4,045	7.96%
Neighbours' military expenditure (% of GDP)	0.03	0.02	3774	271	4,045	6.70%
Neighbours' health expenditure (% of GDP)	0.04	0.02	3774	271	4,045	6.70%
<i>External cause of death</i>						
Transport accident	12.49	6.67	1547	2498	4,045	61.76%
Smoke, fire, flames	1.36	1.88	1547	2498	4,045	61.76%
Falls	5.58	5.85	1547	2498	4,045	61.76%
Drowning and submersion	3.26	3.31	1539	2506	4,045	61.95%
Assault	6.74	9.85	1547	2498	4,045	61.76%
Poisoning	3.48	6.82	1547	2498	4,045	61.76%
All other external cause	9.70	14.23	1541	2504	4,045	61.90%

Table 1 and 2 also show the number of missing values in each variable in the updated data, for the replication of the BGG model and the MSS model, respectively. For the BGG data, except for the World Bank in-house data and the data on donor funding on basic health which we failed to obtain<sup>12</sup> the missing values in the updated data are up to 66% (of 229 countries in the updated data), with the missingness in the illiteracy rate and the rate of paved roads being particularly high. This means that without imputation or without amending the modelling specification we cannot replicate the BGG analysis with a sufficient number of observations. On the other hand, for the MSS data the extent of missingness is relatively moderate: over 10% of observations are missing for all variables (except for 'death by conflict'), and more than 50% of 'primary education enrolment rate' are missing.

Given the large numbers of missing values in the data (for both BGG and MSS), we decide to implement a standard 'multiple imputation by chained equations' (MICE) approach, following Hauck et al. (2015), and available as a STATA command ('mi') (StataCorp, 2013).<sup>13</sup> MICE is a regression based imputation method, in which variables with missing values are regressed on the other variables in the dataset, and then the predicted value of the missing part will be imputed. This procedure is sequentially applied to the other variables with missing values, one at a time. In particular, again following Hauck et al. (2015), we use a predictive mean matching technique

<sup>12</sup> While in the original BGG data, per capita donor funding for health promotion from the Development Assistance Committee (DAC) of the Organization for Economic Co-operation and Development (OECD) in year 1998 (which we failed to update) is used. However, we obtained a qualitatively similar data, i.e. data on per capita amount of Development Assistance for Health (DAH), available at the Institute of Health Metrics and Evaluation database, which we use in the replication analysis of BGG using data from year 2010.

<sup>13</sup> See also Perkins and Neumayer (2014) for an application of MICE in combination with instrumental variables regressions.

(Landerman et al., 1997). According to this technique, a missing value is imputed using non-missing values of samples with similar predictive mean. In the present study we use three neighbours of the predictive mean for the imputation (White et al. 2011). Also, since the data are clustered at country and year level, we take this into account in the analysis by including year and country fixed effects in the imputation equations. Throughout the present paper, we replicate the procedure and generate 50 imputed datasets, and hence conduct 50 separate regression analyses at a time, before the estimates are merged into the final estimation result.<sup>14</sup> Finally, if all values of the variables in the regression models are missing for a country, we drop the country from the analysis.<sup>15</sup>

Although in principle all variables in the regression model should be included in the imputation equation, in the present study we do not impute our instrumental variables in the chained multiple imputation. This is because a key condition in an instrumental variable approach is that instruments should not be correlated directly with outcome variable (capturing the exclusion restriction) (Wooldridge 2010). Imputing the instrumental variables by (partly) using the outcome variable would make it difficult to justify the exclusion restriction. Instead, for the instrumental variables we impute missing values with the mean of the values from neighbouring observations from the same country, i.e. when the value in time  $t$  is missing, we impute the mean of the values in  $t-1$  and  $t+1$ . If all values are missing in the country, we again do not impute the missing values, and therefore that country is dropped from the final estimation sample.

Finally, we assessed the performance of the multiple imputations. We randomly chose 1000 non-missing observations, and artificially dropped them from the working data. We imputed the dropped observations (as well as the originally missing observations) using the MICE technique, and then compared the imputed values with the original non-missing values. For all variables used in the streamlined models, the multiple imputations worked well – the mean difference between the original and imputed value was consistently less than one standard deviation point value of each variable.

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<sup>14</sup> Once the number of replications is specified, this procedure is automatically conducted using the ‘mi’ command in Stata 13 MP. For more detail, see StataCorp (2013). The rule-of-thumb suggests that the number of replications should about correspond to the percentage of missing values in the data. Since less than 50% of the data are missing in our data (Table 1, 2 and 3), the number of replications is considered to be sufficiently large.

<sup>15</sup> In the present study we conduct regression analyses for multiple outcome variables (under-5 mortality and adult mortality) separately. However, in the imputation equation we include the other outcome variable, e.g. we use among other variables under-5 mortality to impute missing values of adult mortality. Also, in the regression analysis we use the imputed dependent variables. We checked the main regression results by not using the imputed dependent variables but instead using the un-imputed dependent variable, and confirmed that our main conclusion is not affected (details not reported here).

## 4. Results

In what follows we first present the results of the replication exercise for each of the two approaches – BGG (section 4.1.1) and MSS (section 4.1.2). Subsequently, we present the results of the streamlined version of either approach – in section 4.2.1 for BGG and in section 4.2.2 for MSS.

### 4.1 Replication results

#### 4.1.1 Replication of BGG

Table 4 starts by replicating the results of the original approaches used in BGG. Column (1) provides the results as they were given in the original paper. As we obtained the original data (as well as the command files) from the authors of both papers, we then tried to replicate the results using exactly the same specification as in the original specification. The results of this replication correspond exactly to those in the original paper. Table 4 also shows additional test statistics for the first stage regression for multiple endogenous variables: in addition to the standard F statistic, we present an augmented F-statistic allowing for multiple endogenous variables (Sanderson and Windmeijer, 2013), as well as Kleibergen and Paap's Wald rk F statistic for under-identification (Kleibergen and Paap, 2006), showing that the instruments are reasonably 'strong' (the rule-of-thumb threshold for F is 10).

As the next step we replace the original data from the BGG paper by the revised data that is available in the relevant data sources as of August 2015, but for exactly the same year that was covered in the paper, i.e. 2000 (see Column (2) in Table 4). This exercise entailed a reduction in the sample size, down from 127 to 66 countries (due to a particularly large number of missing values in the literacy and paved road variables), reducing the comparability of those specific estimates, with respect to the results of the original BGG paper. The reduction in sample size also provides the case for boosting the sample size using imputation methods.<sup>16</sup> We use two different ways of imputation in Table 4 – first we fill the gaps by using BGG's original data directly, wherever the updated data from readily available sources does not have this information (see Column (3)); second, we use a statistical multiple imputation method (MICE) to fill the gaps in the currently available data (see Column (4)).<sup>17</sup> The results in columns (3) and (4) of Table 4 give results that are qualitatively comparable but quantitatively different from the original research – the size of the impacts of the public health expenditure is remarkably larger in the analyses using the updated data with imputation. For under-5 mortality, the original BGG study found that a 1% increase in expenditure will reduce mortality by 0.341% (column (1)). However, when applying MICE to the updated data, the magnitude of the impact is about twice as large as in the original study (the elasticity is -0.601). A similar, but relatively modest increase in the size of the impact is found for maternal mortality (from -0.519 to -0.618). It is important to note that the relevance of the same instrumental variables is now very weak in the updated data, implying the results from the original BGG analysis (1) are more credible than those found in (3) and (4).

<sup>16</sup> BGG's original data are manually imputed using similar data sources (e.g. CIA World Factbook), and by using information from adjacent years, where data for the year of their analysis (2000) was missing. By contrast, here we use a statistical method (i.e. multiple imputations) to impute missing values.

<sup>17</sup> We note that the large number of missing variables comes in the readily available data sources, compared to the data used by BGG, is due to extra-efforts expended by BGG in filling the gaps manually by using information from other data sources (e.g. CIA fact book) and by interpolation, in the case of variables that are likely to not fluctuate much from year to year (e.g. paved roads).

**Table 4: Replication of BGG analysis**

	Under 5 mortality					
	(1)	(2)	(3)	(4)	(5)	(6)
log public health expenditure	-0.341*** (0.127)	-0.810*** (0.245)	-0.502*** (0.178)	-0.570** (0.220)	-1.030*** (0.376)	-0.885** (0.357)
log public health expenditure X donor funding	0.007** (0.003)	0.009 (0.007)	0.009** (0.004)	0.006** (0.002)	-0.009 (0.009)	0.006*** (0.002)
log public health expenditure X paved road	-0.000 (0.000)	-0.002** (0.001)	-0.001*** (0.000)	-0.000 (0.001)	0.001 (0.001)	0.001 (0.001)
log GDP per capita	-0.404* (0.210)	0.174 (0.341)	-0.167 (0.303)	0.191 (0.362)	-0.591 (0.433)	0.246 (0.487)
F for log public health expenditure	10.508	3.337	5.185	5.376	1.525	19.454
F for log public health expenditure X donor funding	135.137	117.490	34.163	23.701	33.040	160.398
F for log public health expenditure X paved road	1407.622	61.444	282.896	103.083	25.112	52.887
F for log GDP per capita	31.596	3.538	4.252	5.311	3.340	7.652
SW-F for log public health expenditure	14.411	4.762	3.538	5.068	3.477	3.295
SW-F for log public health expenditure X donor funding	35.880	10.443	69.138	44.292	5.722	36.843
SW-F for log public health expenditure X paved road	69.637	118.709	52.156	68.523	11.280	29.324
SW-F for log GDP per capita	14.334	4.387	5.508	5.199	3.419	3.442
Kleibergen-Paap Wald statistics	8.534	2.245	2.012	2.557	1.481	1.585
N	127	66	127	127	44	127
	Maternal mortality					
	(1)	(2)	(3)	(4)	(5)	(6)
log public health expenditure	-0.519*** (0.178)	-1.274*** (0.373)	-0.769*** (0.274)	-0.648** (0.275)	-1.729*** (0.595)	-0.922** (0.440)
log public health expenditure X donor funding	0.007 (0.005)	0.016* (0.008)	0.016*** (0.005)	0.009*** (0.003)	0.001 (0.013)	0.006** (0.003)
log public health expenditure X paved road	0.000 (0.000)	-0.002** (0.001)	-0.003*** (0.001)	-0.001 (0.001)	-0.000 (0.002)	0.001 (0.001)
log GDP per capita	-0.440 (0.272)	0.507 (0.484)	0.099 (0.457)	0.051 (0.435)	0.046 (0.705)	0.285 (0.654)
F for log public health expenditure	10.508	3.337	5.185	5.376	1.525	19.454
F for log public health expenditure X donor funding	135.137	117.490	34.163	23.701	33.040	160.398
F for log public health expenditure X paved road	1407.622	61.444	282.896	103.083	25.112	52.887
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SW-F for log GDP per capita	14.334	4.387	5.508	5.199	3.419	3.442
Kleibergen-Paap Wald statistics	8.534	2.245	2.012	2.557	1.481	1.585
N	127	66	127	127	44	127

Notes: Model (1) shows the results as published and replicated; Model (2) shows the results from updated data (year 2000) without imputation; Model (3) shows the results from updated data (year 2000), imputed using the original data where missing; Model (4) shows the results from updated data with multiple imputation; Model (5) shows the results from updated data (year 2010) without imputation; Model (6) shows the results from updated data (year 2010) with multiple imputation.

In Model (5) and (6), since we do not have access to the World Bank in-house data on quality of governance, we impute the variable using the BGG's original data (as of 2000).

In Table 1, non-literate rate and paved road rate exhibit high rates of missing values in the updated data (81.9% and 47.9%, respectively). Since these variables are not likely to vary overtime, we impute the data for 2000 if there are any information available either in 1998, 1999, 2001 and 2002 (two years before and after 2000). The same imputation of the literacy variable is applied to the updated data from 2010.

The BGG original analysis and our replications use data from 2000. In columns (5) and (6) we analyse the updated data for 2010.<sup>18</sup> With and without multiple imputations of the data, the estimated impacts of public health expenditure are greater than the estimated impacts from the 2000 data (in column (6) with multiple imputations, the magnitude of the impact is about -0.9 for both under-5 and maternal mortality).

#### *Sensitivity checks*

By way of sensitivity checks of the above replication analysis using the 2000 data, starting from the original BGG data, we sequentially update only one variable at a time, in order to assess which variable is causing the discrepancies between the estimation result using the original and updated data. The results are summarised in Appendix Table A2 and A3. The size of the impact of public health expenditure displays sensitivity with the impact on under-5 mortality now ranging from -0.257 to -0.459 (Appendix Table A3).

#### **4.1.2 Replication of MSS**

When trying to replicate the results of MSS using the original data (column (1) in Table 5), the model failed to produce the results. By comparing the results to those obtained using an older version of Stata, for which we were able to exactly replicate the original results, it turned out that this significant discrepancy to the original results is the result of an updated version of the Stata code used in the IV fixed effect estimation - `xtivreg2` (Schaffer, 2010; we used the July 2015 version).<sup>19</sup> Therefore we modified the MSS approach in that we dropped three of the four endogenous variables, leaving only our key variable of interest – public health expenditure – as the one endogenous variable. Re-running the MSS model, using exactly the same data as in the original paper, we obtain largely similar coefficients on the public health expenditure variable as in MSS (see column (2) in Table 5).

As was done with the BGG analysis above, we then substitute the original data from the MSS paper by the revised data that is available in the relevant data sources as of August 2015, but for exactly the same years as those covered in the papers, i.e. 1995-2008 (see column (3) of Table 5). Following this procedure produces less robust results compared to those based on the original data: the coefficient of interest remains statistically significant but reverses sign, suggesting a counter-intuitive relationship between expenditures and mortality rates, i.e. health expenditure *increases* mortality. This is likely the result of the less than ideal instruments for mortality (per capita CO2 emission and number of deaths by conflict), as suggested by the very low relevance of the instruments in the first stage regression (F-statistics is less than 4 in all models), reducing the reliability of the estimates.

<sup>18</sup> The descriptive statistics of the 2010 data are presented in Appendix Table C3.

<sup>19</sup> The updated code rejects the model as it detects multi-collinearity between the four instrumental variables used in the first stage regression of the MSS model. We used different versions of - `ivreg2` - and - `ranktest` - commands which are both used within - `xtivreg2` - routine. In the analyses presented throughout the present study is based on - `ivreg2` - version 4.1.08 26 July 2015 and - `ranktest` - version 1.3.05 22 Jan 2015. Using older version of the routine - `ivreg2` - version 2.2.08 15 Oct 2007 and - `ranktest` - 1.1.02 15 Oct 2007, we successfully replicate the results published in the MSS study.



**Table 5: Replication of MSS analysis**

<b>A: Under 5 mortality</b>							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Public health expenditure	-13.193** (0.018)	-13.779** (5.794)	6.759*** (1.915)	-41.302 (37.414)	-0.486 (0.321)	-4.251*** (1.498)	-0.013 (0.082)
Out-of-pocket health expenditure	-6.143 (0.507)	.	.	.	.	.	.
Privately pooled health expenditure	2.685 (0.594)	.	.	.	.	.	.
Immunization coverage	-2.203* (0.073)	.	.	.	.	.	.
1st stage F of reverse causality estimate	3.16	3.070	0.150	0.057	0.770	0.937	1.355
1st stage F of main estimate	.	7.402	21.979	1.285	2630.650	40.332	5.61E+07
Country	153	153	155	159	166	161	163
N	1397	1398	1366	1602	1569	2217	2583
<b>B: Adult female mortality</b>							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Public health expenditure	-2.583** (0.050)	-3.957** (1.552)	12.224** (5.908)	7.483 (4.639)	0.552 (0.468)	-1.041** (0.479)	-0.591* (0.310)
Out-of-pocket health expenditure	5.153 (0.161)	.	.	.	.	.	.
Privately pooled health expenditure	-23.385** (0.040)	.	.	.	.	.	.
Immunization coverage	-9.841** (0.030)	.	.	.	.	.	.
1st stage F of reverse causality estimate	7.19	7.341	3.763	2.321	4.195	3.148	4.985
1st stage F of main estimate	.	4857.69	36.830	34.091	71586589.1	226878.2	110959.4
Country	148	148	154	158	165	160	163
N	1222	1223	1359	1677	1562	2203	2699
<b>C: Adult male mortality</b>							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Public health expenditure	-2.210** (0.025)	-2.944*** (1.026)	8.854** (3.704)	6.148* (3.475)	0.646 (0.552)	-0.620 (0.382)	-0.542** (0.238)
Out-of-pocket health expenditure	8.731 (0.172)	.	.	.	.	.	.
Privately pooled health expenditure	-15.545** (0.016)	.	.	.	.	.	.
Immunization coverage	-7.858** (0.020)	.	.	.	.	.	.
1st stage F of reverse causality estimate	11.60	12.021	2.270	1.487	5.173	1.859	2.615
1st stage F of main estimate	.	13790.4	89.679	52.797	4.216e+08	499648.8	243220.4
Country	148	148	154	158	165	160	163
N	1222	1223	1359	1677	1562	2203	2699

**Notes:**

- Model (1) shows the results as published
- Model (2) shows the results (public health expenditure only) from original data using updated Stata 13 (authors' own estimation)
- Model (3) shows the results from updated data (1995-2008) without imputation
- Model (4) shows the results from updated data (1995-2011) without imputation
- Model (5) shows the results from updated data (1995-2008), imputed using the original data where missing
- Model (6) shows the results from updated data (1995-2008) with multiple imputation
- Model (7) shows the results from updated data (1995-2011) with multiple imputation

However, once we impute the data again, first by filling the (now very few) gaps in the data with values from the original MSS data (Column (5)) and second by using multiple imputation techniques (Column (6) and (7), now with considerably larger sample size), the sign of the coefficients reverse again to the expected direction, but their magnitude still varies considerably between the specifications, and the instruments for mortality continue to be 'weak', i.e. they produce only fairly low F-statistics, according to the benchmarks suggested by Stock and Yogo (2005) and Sanderson and Windmeijer (2013).<sup>20</sup>

<sup>20</sup> In the present analysis we follow Sanderson and Windmeijer's F statistics for relevance of the instruments. If the endogenous variable(s) are just identified i.e. the number of instruments equals the number of endogenous variables, this augmented F statistic coincides with the standard F statistic.

### *Sensitivity checks*

Similarly to section 4.1.1, we assess which variable is causing the discrepancy between the estimation results using the original and updated data, by replacing every variable in the original data with the corresponding variable in the updated data. Appendix Tables A4 and A5 show the results. For under-5 mortality, replacing CO2 emission and GDP per capita lead to counter-intuitive estimates, while for adult female/male mortality, replacing education and public health expenditure lead to counter-intuitive results.<sup>21</sup> Similar to the BGG analysis above, the magnitude of the impact varies considerably upon updating only one variable at a time: the effect estimates range from +1.105 to -14.774 (Appendix Table A5).

## **4.2 Streamlined model analysis**

We develop streamlined models in which we focus on estimating the impact of public health care expenditure using approaches that are broadly (though no longer literally) in line with those employed in the previous literature, including specifically BGG and MSS.

Also, we use a structured approach to select the covariates. The Methods section has outlined the streamlined model in more detail. Table 6 presents the key results of our streamlined models, using different strategies to estimate the causal impacts of public health expenditure: fixed effect instrumental variable approach, pooled cross-section IV approach with additional (time invariant) instruments. Comparing the estimation results with and without the statistical multiple data imputation, we note again the considerable numbers of missing values in the raw data (see Table 3 for more details on missing values).<sup>22</sup>

### **4.2.1 Streamlined model analysis BGG: the ‘traditional IV approach’**

In the case of the traditional IV approach, using the streamlined model, the results do not confirm the large and significant impacts found in the BGG study. In the first stage regression, the relevance of the instrumental variable (log of per capita military expenditure of neighbouring countries) is too weak to identify the causal effect, and hence the large standard errors of the point estimate, making the model essentially invalid.

<sup>21</sup> As explained in the Data section, the original MSS study use per capita GDP in 2005 constant US dollars (PPP adjusted), whereas in the updated data analysis we use per capita GDP in 2011 constant US dollars (PPP adjusted).

<sup>22</sup> The publicly available mortality data are frequently estimated rather than directly observed (Alkema and You, 2012). In order to (partially) avoid the potential problem of serial correlation due to the data estimation, we analysed the same econometric model with more sparse, five-year interval data (1995, 2000, 2005, and 2010). The result is presented in Appendix Table A8. The results are qualitatively similar to the results in Table 6.

**Table 6: Traditional IV and Bruckner IV approach using streamlined model**

	Traditional IV				Bruckner IV			
	Fixed effect		Pooled cross section		Fixed effect		Pooled cross section	
A: log under 5 mortality								
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
log Public health expenditure	0.159 (0.753)	0.682 (0.782)	0.683 (0.629)	0.053 (0.200)	0.110** (0.047)	-0.224** (0.103)	-0.185* (0.098)	-0.063 (0.040)
First stage F of reverse equation	.	.	.	.	1.262	3.707	3.584	2.335
First stage F of main equation	0.245	0.748	0.785	1.761	2323.615	57.13	2413.079	79102.720
Data imputation	No	Yes	No	Yes	No	Yes	No	Yes
N	661	2601	648	2601	666	2631	634	2631
B: log adult female mortality								
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
log Public health expenditure	0.203 (1.102)	0.319 (0.421)	0.025 (0.377)	-0.037 (0.211)	1.836** (0.792)	0.023** (0.012)	-0.063 (0.060)	-0.030 (0.051)
First stage F of reverse equation	.	.	.	.	0.096	4.445	6.940	4.201
First stage F of main equation	0.108	0.748	0.803	1.761	6.040	11345226.8	1424.858	1872.009
Data imputation	No	Yes	No	Yes	No	Yes	No	Yes
N	642	2601	631	2516	647	2590	618	2590
C: log adult male mortality								
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
log Public health expenditure	0.194 (1.188)	0.241 (0.322)	0.147 (0.345)	-0.159 (0.157)	0.337*** (0.077)	-0.148* (0.084)	-0.037 (0.057)	-0.009 (0.031)
First stage F of reverse equation	.	.	.	.	1.293	3.696	8.135	5.004
First stage F of main equation	0.108	0.748	0.803	1.761	82.351	29.99	2050.833	11412.165
Data imputation	No	Yes	No	Yes	No	Yes	No	Yes
N	642	2601	631	2516	647	2590	618	2590

Note: The estimates presented in the columns labelled 'pooled cross section' include more time invariant instrumental variables in addition to original set of time varying instruments. For Traditional IV approach, additional instruments for public health expenditure include the legal origin of the country: British, French, Socialist, German and Scandinavian laws (Rajkumar and Swaroop, 2008; Hu and Mendoza, 2013). For Bruckner IV approach, additional instruments for mortality include indicators of climate zone based on Kopper's classification and malaria ecology index (Lorentzen et al. 2008 and Kizsewski et al. 2004)

### *Sensitivity checks*

Since the results in Table 6 (columns under 'Traditional IV') highlight the limitations in the existing instruments with the updated data, we have sought to improve the quality of the predictive power of the instruments by experimenting with different functional forms of the original instruments and by using alternative ones, following suggestions from the literature. The outcome of this exercise is presented in Appendix Table A6 for the traditional IV approach. Despite these efforts, we fail to find results that would confirm our expectations.

Next, in the streamlined model, per capita GDP is treated as an exogenous variable, whereas in the original BGG specification it is endogenous, and there is hence a concern that this could have led to biased estimates due to model misspecification. To examine this possibility, we conduct an analysis that does treat per capita GDP as another endogenous variable. Following BGG, the consumption-investment ratio was used as the additional instrumental variable for per capita GDP. Appendix Table A9 shows the results. Although it is interesting to see that the models with the multiple imputations show that higher per capita GDP significantly reduces under-5 mortality, we fail to find that public health expenditure reduces mortality outcomes.

### **4.2.2 Streamlined model analysis MSS: the 'Bruckner IV approach'**

As for the Bruckner IV approach, the results using multiple data imputation appear mixed as well, showing the expected negative and statistically significant impacts of public health expenditure in particular for under-5 mortality, though less so for adult mortality (see Table 6 under 'Bruckner IV'). The instrumental variables turn out less relevant in a statistical sense (informed by F statistics of the first stage regression). The magnitude of the elasticity is substantially smaller than what was implied

in the original studies. For instance, where intuitive direction and statistical significance are achieved, the magnitude of the impact on under-5 mortality is -0.224, and that on adult male mortality is -0.148, i.e. a 1% increase in expenditure leads to a reduction of mortality by 0.224 or 0.148%.

#### *Sensitivity checks*

Testing a set of different IVs, in an effort to overcome the limitations in the existing instruments with the updated data (see Appendix Table A7), provides the same conclusions as in the ‘traditional IV’ case above: we obtain insignificant or counter-intuitive results, the relevance of the instruments remains low and the discrepancy to the results in the original studies is large.

### **4.3 Specification and robustness checks**

In Appendix B1, we conduct further specification checks of the analysis based on the streamlined model (both Traditional and Bruckner IV approaches). Notably, the main models presented above have examined the impact of a change in expenditure on a change in mortality in the same year. Also, in the main model we only address the impact of public health expenditure, ignoring other sources of health care spending. First, we investigated the lagged (t-1, t-2, or t-5) impacts of public health expenditure on current mortality outcomes, with only one lag-specification included at a time. Also, we examined the impact of total health expenditure (public and private expenditure). For more detailed description, see Appendix B.1. The results of the analyses are presented in Appendix Table B1. For the Traditional IV approach, again the estimation results are not reliable due to low F statistics. For the Bruckner IV approach, when multiple imputation is applied, we again find a small, negative and statistically significant impact for under-5 mortality – the size of elasticity is around -0.1 to -0.2 for t-1, t-2 and t-5 models, and the impact diminishes upon increasing the number of lags. For adult female and male mortality, the effect is even smaller and statistically indistinguishable from zero. Similarly, the impacts of total expenditure were not statistically significant or intuitive, except for the case of Bruckner’s IV approach (see Block D, Column (4) of Table B1), where the elasticity of (current) total health expenditure on under-5 mortality is about -0.3.

We then allow for lagged structure in the estimation of the impact of expenditure. We include current and lagged health expenditure (t-1, t-2 and t-3) *in the same econometric model* and estimated the conditional impacts of expenditure at each period on current mortality outcomes. The results are summarised in Appendix Table B2. The results from the Traditional IV approach show non-significant impacts of contemporaneous as well as any lagged public health expenditure in all models. For the Bruckner IV approach, when the multiple imputations are applied, the impact of contemporaneous public health expenditures (column (4)) is negative and statistically significant for under-5 mortality and adult male mortality. However, the impacts of lagged public health expenditure (conditional on contemporaneous expenditure) are small and largely statistically insignificant.

The final set of specification checks involves different assumptions for the identification of causal impacts. Although in the main analysis we use instruments that were demonstrated to be statistically relevant in the previous cross-country data studies, we fail to confirm this in the updated data and in the streamlined model specification. This could suggest that alternative analytic approaches are called for that do not rely on the identification of suitable external instruments. Following this idea, we pursue two approaches: first, we use lagged health expenditure to avoid reverse causality while still using fixed effect modelling to take into account time-invariant country heterogeneity<sup>23</sup>; second, we incorporate a dynamic structure into the model and construct a set of

<sup>23</sup> We make a stronger assumption about exogeneity of lagged health expenditure here than the previous models presented in this section. In fact, lagged health expenditure is predetermined but not necessarily exogenous.

IVs from observations from previous years – a dynamic panel data approach (Blundell and Bond, 1998). The results of the estimations from the two approaches, with and without the data imputation, are presented in Table Appendix B3. In the table, Block A, B and C use only fixed effect effects to estimate the effect of contemporaneous and lagged health expenditure. In Block D, the estimates from Blundell-Bond estimation are presented. The estimates of the impact of health expenditure turn out rather mixed, though overall the magnitudes of the impacts, whether statistically significant or not, are much smaller than expectations based on the results from BGG and MSS.<sup>24</sup>

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<sup>24</sup> The results of the model using the imputed data should be interpreted with caution. As P-values of AR tests indicate, there is no second-order serial correlation. However, the Hansen test indicates that the over-identifying restriction is not valid, meaning that some of the IVs are endogenous.

## 5. Discussion

In this paper we have sought to comprehensively re-examine the robustness of the empirical relationship between public health care spending and mortality outcomes using cross-country data, as it was presented in the main approaches used by the previous literature. We have based our analysis on the data and approaches embodied by two recent key publications in the field – by Bokhari et al. (2007) and Moreno-Serra and Smith (2015). We started by quite successfully replicating the published results, using the exact same data used by the studies. Results were more nuanced once we made use of data for the same year(s) as in the original study but available from publicly accessible sources at the time of data retrieval (August 2015). In ‘updating’ the data in this way, while still following the specific estimation strategies from the original papers, we also employed different imputation strategies to fill major data gaps for some variables. On the whole we found the BGG-based results to still hold qualitatively, though with increased effect size and with weaker performance of the instruments. By contrast, the MSS-based results were substantively affected, and the relevance of the instruments did deteriorate, producing less resemblance to the original results. Across the two studies, in the majority of replication scenarios the effect of public health care expenditure on mortality was found to be negative, although qualitative conclusions based on statistical significance vary and the magnitude of the impact is sensitive to revisions and updates in the data used.<sup>25</sup>

In a further step, we abstracted from the specific estimation strategies in the original papers, among others in order to follow the ‘spirit’ of the approaches used, without the need for overly strict adherence to their idiosyncratic features, and in order to capture some commonalities with other previous studies in this field. We thus constructed our ‘streamlined’ versions of the two approaches, complemented by a battery of robustness checks, as well as some changes to the specifications to accommodate certain other empirical approaches used in the literature (e.g. dynamic panel analysis). In sum, the results showed that in the traditional IV model our instrument for public health care expenditure (per capita military expenditure of neighbouring countries) is not statistically relevant and thus the IV estimation coefficients become unreliable. For the Bruckner IV streamlined model, at least in some cases the estimated effects were broadly consistent with the previous literature, finding that public spending reduced mortality, although at generally lower effect magnitudes and with mixed degrees of statistical significance.

Our very mixed findings should not be taken to imply that the conclusions from the previous studies are necessarily invalid. Countries covered in the published data and in our updated data do indeed differ and therefore it is to be expected that the analysis leads to different conclusions. Nevertheless, our findings do highlight the potential lack of generalisability of the results to different settings.

Our conclusions need to be seen in the light of the considerable methodological challenges faced by this strand of research, many of which may form the basis of a potential research agenda in this area, as discussed below.

### 5.1 Data limitations

The data used for the replication of the two key papers have been obtained directly from the authors of the paper in the case of Bokhari et al (2007) and from data made available via the web appendix for the Moreno Serra & Smith (2015) paper. With very few exceptions, this data is in principle available from readily and freely accessible data sources, e.g. the WHO’s Global Health

<sup>25</sup> Similar sensitivities of the results to updates in the underlying data have been encountered by Easterly et al. (2004), Roodman (2008), Clemens et al. (2012), and Roodman (2015) in the context of replicating the results from the literature on the impact of aid on economic growth.

Observatory and the World Bank's World Development Indicators. These (as well as several other publicly accessible databases) are also the data sources we have used when updating and expanding the data employed in our empirical estimates. While the data from these sources represent the most comprehensive ones available and have been (and most certainly will be) used in numerous well-published studies<sup>26</sup>, they are not without quality concerns that may affect the reliability of our impact estimates. This is the case despite the considerable and laudable efforts that international organizations or research institutes have invested to try and establish common standards of how data should be defined and collected. The degree to which quality issues are present will vary by indicator and across countries. For instance, the data collection for one of our key variables – GDP per capita – should be approximately similar across countries given longstanding efforts to ensure consistent definition of this measure.

Measurement error is likely more severe in the case of our key independent variable (i.e. public health expenditures). As the WHO's methodological background note (World Health Organization, 2012) to their Global Health Expenditure database acknowledges, there are major gaps in the data delivered to WHO from countries (which, if it is delivered, is typically taken on at face value), with the gaps then being filled by various forms of interpolation<sup>27</sup>, extrapolation, imputation and estimation.

Random measurement error in the health expenditure variable would normally bias the estimates of the impact on mortality towards the null, while random measurement error in our dependent variable (mortality) would produce higher standard errors of the impact estimates, reducing the statistical significance of the results (Wooldridge, 2010).<sup>28</sup> As health expenditure enters as a right hand side variable in our regression model, it is likely that a valid instrumental variable strategy could reduce some of the bias resulting from such measurement error. In our case though, for many of the empirical models the instruments used were weak – and it is this that has arguably been a far greater problem in our set of estimates, compared to data quality issues. Moreover, there are at least two sources of measurement error – one embedded in the numbers reported to the data collecting agencies (i.e. WHO), and an additional one as a result of the (not always fully replicable) imputation approaches adopted by such agencies. In this case it is at least conceivable (though very hard to tell for certain) that measurement error in the health expenditure variable may account for the weakness of the instrumentation in the first stage estimates.

Arguably, measurement error is far more severe in the case of our dependent variables of interest, i.e. the under-5 and gender-specific adult mortality-rates – the underlying problem being the often complete absence of functioning vital registration systems in particular in many low income countries (Alkema and You, 2012). In response, an impressive research 'industry' has emerged, developing and applying sophisticated modelling methods to fill the mortality data gaps statistically. The fact that different research teams find considerable differences in, for instance, their under-5 mortality estimates for many LMICs does, however, underscore the measurement problem at hand. Short of obtaining the 'perfect' data (which will never happen), there are, however, ways in which more purposefully selected, specific data sources would be worthwhile using, if there is reason to believe that they provide better quality data, and even at the cost of reducing the country coverage. Examples on the mortality side might include using data from Demographic and Health Surveys only or on the expenditure side to focus on information from detailed IMF Government Finance Statistics, the World Bank's Poverty Assessments and Public Expenditure Reviews (see e.g. Gupta et al., 2003).

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<sup>26</sup> The literature in other development areas, e.g. on the role of aid on economic growth, has been shown to suffer from similar data challenges (Easterly et al. 2004; Roodman, 2008).

<sup>27</sup> Given that some of the original variables are estimated using previous years' observations, in Appendix Table A8 we present the same analysis based on the streamlined model where we use quinquennial data.

<sup>28</sup> Note also that in case the measurement error is non-random but constant over time, then the fixed effects approach would resolve this problem.

## 5.2 Methodological limitations

There are at least three methodological issues to be borne in mind.

First, following the previous literature that predominantly accounts for country-level heterogeneity and for endogeneity of health expenditure and mortality, we have employed a panel fixed effect approach, combined with instrumental variables techniques. Incorporating country fixed effect in the model means that we compromise statistical power because the estimation relies only on within-country variations in health care expenditure and mortality. Because there are relatively small variations in these variables over time, and also because the analysis often relies on ‘weak’ instrumental variables, our methods (though being standard in the literature) may be of insufficient power to statistically detect the impact. This potential downside of the fixed-effect approach, however, has to be weighed up against the likely considerable benefits of controlling more adequately for endogeneity through the regression control over unobserved heterogeneity in time-invariant characteristics and also in factors that change slowly over time such as cultural factors or the quality of institution.

Second, our results using the multiple imputations (MI) should be interpreted with caution. Although MI has been widely adapted in the applied statistic literature, its applications in health econometric models (in particular as part of instrumental variables approaches) have been rare (Perkins and Neumayer, 2014). We carefully construct our imputation so that it does not violate the exclusion restriction assumption in the IV approach. Yet detailed statistical properties of the application of the MI approach should be expanded upon in future research. That said, and as we showed, the alternative of not imputing the data would mean that the econometric analysis would have to do without a considerable number of countries with any missing values in the model specifications, producing a highly unrepresentative sample and causing selection bias, the impacts of which in terms of main effects are a priori unknown (though likely significant). At the same time, it must be noted that the statistical imputation increases the likelihood of measurement error in the regressions, thereby augmenting the impact estimates as well as the standard errors.

Third, the instrumental variable technique has been the standard workhorse for causal analysis in the relevant literature. As in the present study, the validity and relevance of the instruments can generally be questioned – i.e. some instruments occasionally prove to be good in a statistical sense, but that could be sensitive to choice of data and other variables in the model. Furthermore, it should be noted that the instrumental variable approach does not necessarily provide average treatment effects (ATE), which would be the key quantity of interest, but instead it gives the local average treatment effect (LATE), in which the impact of health expenditure is identified only for the subset of countries for which expenditure is *actually* affected by the instruments (Angrist and Imbens, 1995; Angrist et al., 1996). In the literature it is common to assume homogeneity of the IV impact, rather than allowing for heterogeneity of the impacts across countries, so that the estimated IV impacts conveniently represents ATE, despite that in practice it is hard to believe that the impacts of expenditure will be common across countries. For simplicity, the present study, as well as the previous studies in the literature, focuses on homogeneous impacts and abstains from discussing likely differences between the ATE and LATE in this context.

## 5.3 Policy implications

The primary policy question is whether or not greater public health care expenditures improve population health. The two prominent studies – BGG and MSS – claim that health expenditures do reduce mortality, and that the magnitude of the effect is considerable, hence supporting greater publicly funded health coverage across countries. However, the cross-country based work presented here (as well as some of previous research, e.g., Filmer and Pritchett 1999) shows that the



magnitude and precision of this effect is sensitive to the choice of data and econometric methods. Our results do not necessarily suggest that policies expanding public health expenditure do not save lives at all. Rather, our results confirm the common problems in cross-country data analysis – that the noise in the cross country data may be so large that the current econometric methods could sometimes fail to robustly detect the health gains at global level.

Another important implication of the analysis would be the extent to which our estimates reliably inform marginal productivity of healthcare systems across countries – the key variable that would be needed to inform country-specific cost-effectiveness thresholds (Ochalek et al 2015). In light of the limited robustness to changes in model specification and in data of the empirical findings, coupled with imprecise estimation (due to weak IVs), our results again may not uncover the true (if any) productivity of healthcare systems across countries, and therefore further improvement in either data, empirical methods, or even research design are required.<sup>29</sup>

#### **5.4 Implications for future research**

Future research should involve the improvement in both the methods for the analysis of cross country data and in data quality. Global efforts to obtain finer data should improve the data quality over time. Some arguably ‘better’ data already exists, if at the cost of a considerably smaller sample of countries; for example, international household surveys (e.g. the World Bank’s Living Standard Measurement Surveys) do provide finer data on health and household healthcare spending at more granular level (e.g. observations at household level), which could potentially overcome some of the key limitations in the cross country data.

Since the impact of public health expenditure on mortality could also be heterogeneous across countries, future research should explore such heterogeneity. The BGG model does allow for differential impacts, conditional on the level of economic development (proxied by the proportion of paved roads) and on the amount of donor funding for health. Using the updated data for the year 2000 in the BGG specification, Appendix Figure A1 summarises the distribution of the impacts of public health expenditure on mortality. We find that the impacts for under-5 mortality are considerably more homogenous than for maternal mortality. Similarly, Wagstaff and Claeson (2004) found that the mortality-reducing impact of public expenditure becomes evident only once the quality of governance exceeds a certain threshold level. It may hence be worthwhile to assess possible additional factors that mitigate or promote the impact of public health expenditure, including, for instance, baseline mortality. Quantile treatment effect models could be useful to test and quantify the impacts of public health expenditure across countries (Chernozhukov, and Hansen 2005).

Another possibility would be to use within-country data to investigate the domestic impact of health expenditure on health outcomes. Although there are some such research in high income countries (for example, Martin et al., 2008; Card et al., 2009; Claxton et al., 2015), the evidence is still limited in LMICs, where policy issues relating to universal health coverage become more relevant and also healthcare resources are generally scarce, except for some existing studies in major countries such as India (Bhalotra, 2007; Farahani et al., 2010).

At the same time, our findings add further weight to the case for journals to require authors to submit their data along with their paper, so that the data becomes permanently available to future

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<sup>29</sup> An online tool based on Ochalek et al. (2015) has been made available at: <https://www.york.ac.uk/media/che/documents/Calculating%20cost%20per%20DALY%20averted%20thresholds%20for%20LMICs.xlsm>, which enables users to enter new estimates of the elasticity of health outcomes with respect to public health care expenditure, or to carry out sensitivity analysis when using existing published estimates when estimating cost-effectiveness thresholds for LMICs.

scholars, thereby allowing for the discrepancies resulting from retrospective corrections to be traced to changes in the data. The problem we encountered when trying to replicate the exact original MSS results using an updated, revised version of a Stata command (`xtivreg2`) also suggest that whenever authors use a public-domain user-written program, that the journal should require them to post the program as well as the data and relevant Do-files.

Likewise, the agencies producing and publishing the data would benefit research by making available each version of the data, rather than just the latest one that would supersede all previous ones. The producers of such data could also usefully increase the degree of transparency about the exact methods that have been used in imputing gaps in the underlying data, and indeed the extent to which imputation has been undertaken.

Finally, the current literature is largely based on an instrumental variable approach in estimating causal impacts of health expenditure, despite the fact that instruments could be sometimes questioned (even if statistically relevant occasionally, they are not always theoretically convincing). An alternative approach would be to use actual policy variations in healthcare expenditure to inform the impact estimation. Examples of sources of such variations include expansion of public insurance schemes (see Acharya et al., 2012 for a comprehensive review), funding decision rules in healthcare (Dykstra et al., 2015), and large scale field or natural experiments that involve the provision of additional healthcare resources/funding (Wagstaff, 2011; Olken et al., 2014). Carefully evaluating those policy and experimental shocks on expenditure could possibly provide more transparent and robust evidence.

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## Appendix A

- Table A 1: List of sources of updated data
- Table A 2: BGG analysis using the original data
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- Table A 6: Traditional IV approach (with streamlined model) using different specifications of instrumental variables
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- Table A 8: Regression analysis based on data from 1995, 2000, 2005, and 2010 only (replication of the analysis in Table 6, first column with fixed effect IV model)
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**Table A 1: List of sources of updated data**

Variable	Description	Database	URL
Public health expenditure	General government expenditure on health in constant 2010 US\$ per capita, PPP	World Health Organization, Global Health Expenditure Data Base	<a href="http://apps.who.int/nha/database/ViewData/Indicators/en">http://apps.who.int/nha/database/ViewData/Indicators/en</a>
Total health expenditure	Total expenditure on health in constant 2010 US\$ per capita, PPP	World Health Organization, Global Health Expenditure Data Base	<a href="http://apps.who.int/nha/database/ViewData/Indicators/en">http://apps.who.int/nha/database/ViewData/Indicators/en</a>
Private health insurance	Private insurance in constant 2010 US\$ per capita, PPP	World Health Organization, Global Health Expenditure Data Base	<a href="http://apps.who.int/nha/database/ViewData/Indicators/en">http://apps.who.int/nha/database/ViewData/Indicators/en</a>
Out of pocket health expenditure	Out of pocket expenditure in constant (2005) US\$ per capita, PPP	World Health Organization, Global Health Expenditure Data Base	<a href="http://apps.who.int/nha/database/ViewData/Indicators/en">http://apps.who.int/nha/database/ViewData/Indicators/en</a>
Immunization: measles	Immunization, measles (% of children ages 12-23 months)	World Bank, World Development Indicators database	<a href="http://data.worldbank.org/indicator/SH.IMM.MEAS/countries">http://data.worldbank.org/indicator/SH.IMM.MEAS/countries</a>
Immunization coverage (other than measles)	WHO/UNICEF coverage estimates for 1980-2014, as of July 2015.; Reported official target population, number of doses administered and official coverage	World Health Organization, Immunization, Vaccines and Biologicals Data	<a href="http://www.who.int/immunization/monitoring_surveillance/data/en/">http://www.who.int/immunization/monitoring_surveillance/data/en/</a>
Adult female mortality rate	Mortality rate, adult, female (per 1,000 female adults)	World Bank, World Development Indicators database	<a href="http://data.worldbank.org/indicator/SP.DYN.AMRT.FE">http://data.worldbank.org/indicator/SP.DYN.AMRT.FE</a>
Adult male mortality rate	Mortality rate, adult, male (per 1,000 male adults)	World Bank, World Development Indicators database	<a href="http://data.worldbank.org/indicator/SP.DYN.AMRT.MA">http://data.worldbank.org/indicator/SP.DYN.AMRT.MA</a>
Under 5 mortality rate (UN estimate)	Mortality rate, under-5 (per 1,000 live births)	World Bank, World Development Indicators database	<a href="http://data.worldbank.org/indicator/SH.DYN.MORT">http://data.worldbank.org/indicator/SH.DYN.MORT</a>
Under 5 mortality rate (IHME estimate)	Mortality rate, under-5 (per 1,000 live births): Infant and Child Mortality Estimates by country	Institute of Health Metrics and Evaluation, Global Health Data Exchange	<a href="http://ghdx.healthdata.org/record/infant-and-child-mortality-estimates-country-1970-2010">http://ghdx.healthdata.org/record/infant-and-child-mortality-estimates-country-1970-2010</a>
Maternal mortality rate	Maternal mortality ratio (modeled estimate, per 100,000 live births)	World Bank, World Development Indicators database	<a href="http://data.worldbank.org/indicator/SH.STA.MMRT">http://data.worldbank.org/indicator/SH.STA.MMRT</a>
Gross domestic product (GDP)	GDP per capita, constant 2011 US\$, PPP	World Bank, World Development Indicators database	<a href="http://data.worldbank.org/indicator/NY.GDP.PCAP.KD">http://data.worldbank.org/indicator/NY.GDP.PCAP.KD</a>
Primary education enrollment rate	Adjusted net enrollment rate, primary (% of primary school age children)	World Bank, World Development Indicators database	<a href="http://data.worldbank.org/indicator/SE.PRM.TENR?page=4&amp;display=default3Fiframe3Dtrue">http://data.worldbank.org/indicator/SE.PRM.TENR?page=4&amp;display=default3Fiframe3Dtrue</a>



**Table A 1: List of sources of updated data (continued)**

Variable	Description	Database	URL
Population aged 0-14	Population ages 0-14 (% of total)	World Bank, World Development Indicators database	<a href="http://data.worldbank.org/indicator/SP.POP.0014.TO.ZS">http://data.worldbank.org/indicator/SP.POP.0014.TO.ZS</a>
Population aged 65+	Population ages 65 and above (% of total)	World Bank, World Development Indicators database	<a href="http://data.worldbank.org/indicator/SP.POP.65UP.TO.ZS">http://data.worldbank.org/indicator/SP.POP.65UP.TO.ZS</a>
CO2 emission per capita	CO2 emissions (metric tons per capita)	World Bank, World Development Indicators database	<a href="http://data.worldbank.org/indicator/EN.ATM.CO2E.PC">http://data.worldbank.org/indicator/EN.ATM.CO2E.PC</a>
Battle related deaths	Number of battle-related deaths by country	Uppsala University, UCDP Battle-related Deaths dataset	<a href="http://www.pcr.uu.se/research/ucdp/datasets/ucdp_battle-related_deaths_dataset/">http://www.pcr.uu.se/research/ucdp/datasets/ucdp_battle-related_deaths_dataset/</a>
WHO external cause of death	8 indicators of deaths which are externally caused	World Health Organization, Global Health Expenditure Data Base	<a href="http://www.who.int/healthinfo/mortality_data/en/">http://www.who.int/healthinfo/mortality_data/en/</a>
WDI worldwide governance indicators	governmental performance	World Bank, Worldwide Governance Indicators data	<a href="http://info.worldbank.org/governance/wgi/index.aspx#home">http://info.worldbank.org/governance/wgi/index.aspx#home</a>
Total population	Population, total	World Bank, World Development Indicators database	<a href="http://data.worldbank.org/indicator/SP.POP.TOTL">http://data.worldbank.org/indicator/SP.POP.TOTL</a>
SIPRI military expenditure	Military expenditure in 2011 constant USD	Stockholm International Peace Research Institute Military Expenditure Database	<a href="http://www.sipri.org/research/armaments/milex/milex_data_base">http://www.sipri.org/research/armaments/milex/milex_data_base</a>
Legal origins of country	Legal origins of countries (British, French, Socialist, German, and Scandinavian)	World Bank Global Development Network Growth Database: Lost decades social indicators and fixed factors	<a href="http://econ.worldbank.org/WBSITE/EXTERNAL/EXTDEC/EXTRESEARCH/0,,contentMDK:20701055~pagePK:64214825~piPK:64214943~theSitePK:469382,00.html">http://econ.worldbank.org/WBSITE/EXTERNAL/EXTDEC/EXTRESEARCH/0,,contentMDK:20701055~pagePK:64214825~piPK:64214943~theSitePK:469382,00.html</a>
Urban population rate	Urban population (% of total)	World Bank, World Development Indicators database	<a href="http://data.worldbank.org/indicator/SP.URB.TOTL.IN.ZS">http://data.worldbank.org/indicator/SP.URB.TOTL.IN.ZS</a>
Sanitation rate	Improved sanitation facilities (% of population with access)	World Bank, World Development Indicators database	<a href="http://data.worldbank.org/indicator/SH.STA.ACSN">http://data.worldbank.org/indicator/SH.STA.ACSN</a>
Paved road rate	% paved road	United Nations Database (mirroring World Development Indicators database)	<a href="http://data.un.org/Data.aspx?d=WDI&amp;f=Indicator_Code%3AIS.ROD.PAVE.ZS">http://data.un.org/Data.aspx?d=WDI&amp;f=Indicator_Code%3AIS.ROD.PAVE.ZS</a>
Literacy rate	literacy rate (% of people ages 15 and above)	World Bank, World Development Indicators database	<a href="http://data.worldbank.org/indicator/SE.ADT.LITR.ZS">http://data.worldbank.org/indicator/SE.ADT.LITR.ZS</a>
Primary education completion rate	% of the total population of the theoretical entrance age to the last grade of primary education	World Bank, World Development Indicators database	<a href="http://data.worldbank.org/indicator/SE.PRM.CMPT.ZS">http://data.worldbank.org/indicator/SE.PRM.CMPT.ZS</a>
Donor funding on basic health	Development assistance for health (DAH)	Institute of Health Metrics and Evaluation, Global Health Data Exchange	<a href="http://ghdx.healthdata.org/record/development-assistance-health-database-1990-2014">http://ghdx.healthdata.org/record/development-assistance-health-database-1990-2014</a>
Consumption-investment ratio	Investment Share of PPP Converted GDP Per Capita at 2005 constant prices	University of Pennsylvania, Penn World Tables	<a href="https://pwt.sas.upenn.edu/php_site/pwt71/pwt71_form.php">https://pwt.sas.upenn.edu/php_site/pwt71/pwt71_form.php</a>

Table A 2: BGG analysis using the original data (replacing every variable from updated data sequentially)

	Variable replaced								
	Under 5 mortality	Maternal mortality	GDP per capita	Public health expenditure	Neighbours military expenditure per capita	Investment- GDP ratio	Nonliteracy rate	Paved road rate	Sanitation rate
<b>A. Under 5 Mortality</b>	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Public health expenditure	-0.459*** (0.130)	-0.341** (0.132)	-0.339*** (0.127)	-0.289** (0.132)	-0.268* (0.147)	-0.338** (0.135)	-0.464* (0.253)	-0.323 (0.208)	-0.342*** (0.129)
First stage F	14.411	14.411	9.643	3.263	13.060	14.821	2.949	7.777	16.795
N	127	127	125	126	127	127	33	81	125
<b>B. Adult female mortality</b>	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Public health expenditure	-0.519*** (0.184)	-0.613*** (0.185)	-0.517*** (0.169)	-0.355* (0.210)	-0.454** (0.179)	-0.523*** (0.177)	-0.750** (0.353)	-0.731** (0.285)	-0.508*** (0.172)
First stage F	14.411	14.414	9.643	3.263	13.060	14.821	2.949	7.777	16.795
N	127	125	125	126	127	127	33	81	125

[illegible]

Table A 4: MSS analysis using the original data (replacing every variable from updated data sequentially)

	Variable replaced									
	CO2 emission	Conflict death	Education	GDP per capita	Public health expenditure	Adult female mortality	Adult male mortality	Under 5 mortality	Population under 14	Population over 65
<b>A. Under 5 Mortality</b>	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Public health expenditure	1.105*** (0.325)	-17.663** (8.050)	-9.323** (3.755)	2.496*** (0.615)	-14.774** (6.342)	-13.779** (5.794)	-13.779** (5.794)	-13.779** (5.794)	-14.165** (6.029)	-12.671** (5.187)
First stage F of reverse equation	2.818	1.842	0.485	1.197	3.070	3.070	3.070	3.070	2.870	2.703
First stage F of main equation	16316.984	5.783	10.581	582.578	6.447	7.402	7.402	7.402	7.145	8.040
N	1404	1398	1346	1375	1398	1398	1398	1398	1398	1398
<b>B. Adult female mortality</b>	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Public health expenditure	-4.785** (1.935)	-2.523*** (0.943)	5.007 (3.297)	-5.778** (2.601)	-2.818** (1.130)	-27.641** (12.696)	-3.957** (1.552)	-3.957** (1.552)	-1.158* (0.689)	-2.667*** (1.000)
First stage F of reverse equation	7.485	14.846	0.571	8.447	7.341	3.991	7.341	7.341	6.333	7.304
First stage F of main equation	1904.345	57128.000	236.640	533.398	7759.480	10.180	4857.691	4857.691	5751295.449	37410.162
N	1229	1223	1165	1204	1223	1398	1223	1223	1223	1223
<b>C. Adult male mortality</b>	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Public health expenditure	-4.954*** (1.841)	-1.927*** (0.670)	2.010 (1.369)	-4.766** (1.890)	-14.774** (6.342)	-2.944*** (1.026)	-19.772** (7.745)	-2.944*** (1.026)	-0.794 (0.532)	-1.745*** (0.655)
First stage F of reverse equation	11.767	17.764	0.880	14.104	3.070	12.021	6.542	12.021	10.708	11.880
First stage F of main equation	1091.073	155334.965	3138.602	874.922	6.447	13790.401	19.354	13790.401	1095374.893	183319.494
N	1229	1223	1165	1204	1398	1223	1398	1223	1223	1223

**Table A 5: MSS analysis using the original data (replacing every variable from updated data sequentially): updated data are imputed using original data where missing**

	Variable replaced									
	CO2 emission	Conflict death	Education	GDP per capita	Public health expenditure	Adult female mortality	Adult male mortality	Under 5 mortality	Population under 14	Population over 65
<b>A. Under 5 Mortality</b>	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Public health expenditure	1.105*** (0.325)	-17.663** (8.050)	-4.335*** (1.573)	3.121*** (0.778)	-14.774** (6.342)	-13.779** (5.794)	-13.779** (5.794)	-13.779** (5.794)	-14.165** (6.029)	-12.671** (5.187)
First stage F of reverse equation	2.818	1.842	4.249	1.558	3.070	3.070	3.070	3.070	2.870	2.703
First stage F of main equation	16316.984	5.783	36.995	217.160	6.447	7.402	7.402	7.402	7.145	8.040
N	1404	1398	1512	1398	1398	1398	1398	1398	1398	1398
<b>B. Adult female mortality</b>	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Public health expenditure	-4.785** (1.935)	-2.523*** (0.943)	-5.186** (2.153)	-6.245** (2.796)	-2.818** (1.130)	-27.641** (12.696)	-3.957** (1.552)	-3.957** (1.552)	-1.158* (0.689)	-2.667*** (1.000)
First stage F of reverse equation	7.485	14.846	6.796	7.842	7.341	3.991	7.341	7.341	6.333	7.304
First stage F of main equation	1904.345	57128.000	1018.047	412.293	7759.480	10.180	4857.691	4857.691	5751295.449	37410.162
N	1229	1223	1320	1223	1223	1398	1223	1223	1223	1223
<b>C. Adult male mortality</b>	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Public health expenditure	-4.954*** (1.841)	-1.927*** (0.670)	-4.887*** (1.792)	-5.390** (2.096)	-14.774** (6.342)	-2.944*** (1.026)	-19.772** (7.745)	-2.944*** (1.026)	-0.794 (0.532)	-1.745*** (0.655)
First stage F of reverse equation	11.767	17.764	11.404	12.536	3.070	12.021	6.542	12.021	10.708	11.880
First stage F of main equation	1091.073	155334.965	1073.583	620.003	6.447	13790.401	19.354	13790.401	1095374.893	183319.494
N	1229	1223	1320	1223	1398	1223	1398	1223	1223	1223

**Table A 6: Traditional IV approach (with streamlined model) using different specifications of instrumental variables**

	Unimputed model				Imputed model			
A: Under 5 mortality								
	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
log Public health expenditure	-0.048 (0.310)	-0.003 (0.291)	0.038 (0.266)	0.193 (1.801)	1.069 (1.413)	0.035 (0.265)	-0.060 (0.196)	0.560 (1.912)
First stage F	0.664	0.707	0.503	0.079	0.506	1.564	3.221	0.157
N	661	661	661	661	2601	2601	2601	2601
B: Adult female mortality								
	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
log Public health expenditure	-0.118 (0.420)	-0.315 (0.439)	-0.264 (0.410)	-0.303 (1.470)	0.381 (0.526)	0.271 (0.245)	0.233 (0.189)	0.448 (1.373)
First stage F	0.546	0.757	0.537	0.076	0.506	1.564	3.221	0.157
N	642	642	642	642	2601	2601	2601	2601
C: Adult male mortality								
	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
log Public health expenditure	-0.174 (0.354)	-0.447 (0.344)	-0.471 (0.347)	-0.501 (1.507)	0.284 (0.410)	0.328 (0.218)	0.312* (0.169)	0.802 (1.790)
First stage F	0.546	0.757	0.537	0.076	0.506	1.564	3.221	0.157
N	642	642	642	642	2601	2601	2601	2601

Notes:

IVs in the main model (Table 6 of the main paper) are log neighbours military expenditure as % of GDP, and log neighbours public health expenditure as % of GDP.

- Model (1) uses Raw IV (note that main model in Table 6 used logged IVs)
- Model (2) adds squared raw IV to model (1)
- Model (3) further adds cubic raw IV to model (2)
- Model (4) uses total neighbours military and public health expenditure (not per capita expenditure)

**Table A 7: Bruckner IV approach (with streamlined model) using different specifications of instrumental variables**

	Unimputed model				Imputed model			
<b>A: Under 5 mortality</b>								
	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
log Public health expenditure	-0.765*** (0.157)	-0.493*** (0.092)	-0.227*** (0.045)	-0.040 (0.050)	-0.272** (0.120)	-0.193** (0.091)	-0.060 (0.039)	-0.117*** (0.035)
First stage F of reverse equation	1.679	0.845	1.322	1.199	1.836	1.324	1.597	2.562
First stage F of main equation	51.819	141.607	1355.738	12557.842	36.317	85.065	3427.838	8886.840
N	669	669	669	392	2631	2631	2631	1214
<b>B: Adult female mortality</b>								
	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
log Public health expenditure	-0.262*** (0.060)	-0.237*** (0.056)	-0.305*** (0.068)	0.039 (0.036)	-0.240** (0.121)	-0.117* (0.068)	-0.049 (0.039)	0.122*** (0.046)
First stage F of reverse equation	2.432	1.686	2.356	3.826	1.975	5.044	3.792	1.297
First stage F of main equation	252.397	331.238	172.733	14293.717	19.599	89.859	693.625	808.783
N	650	650	650	376	2590	2590	2590	1182
<b>C: Adult male mortality</b>								
	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
log Public health expenditure	-0.346*** (0.070)	-0.192*** (0.048)	-0.263*** (0.058)	-0.016 (0.035)	-0.392*** (0.145)	-0.301** (0.125)	-0.086 (0.064)	0.079*** (0.027)
First stage F of reverse equation	1.139	1.693	3.137	4.676	1.180	2.990	2.095	1.371
First stage F of main equation	102.915	360.303	172.024	378266.2	14.540	15.566	67.351	2690.143
N	650	650	650	376	2635	2635	2635	1214

Notes:

IVs in the main model (Table 6 of the main paper) are log per capita CO2 emission; and log number of deaths by conflict

- Model (1) uses Raw IV (note that main model in Table 6 used logged IVs)
- Model (2) adds squared raw IV to model (1)
- Model (3) further adds cubic raw IV to model (2)
- Model (4) uses main IV (CO2 and Conflict deaths) plus log of external causes of deaths

**Table A 8: Regression analysis based on quinquennial data (replication of the analysis in Table 6, first column with fixed effect IV model)**

	Traditional IV				Bruckner IV			
<b>A: log under 5 mortality</b>	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
log Public health expenditure	-0.709 (0.584)	-0.522 (7.415)	0.365 (0.542)	0.498 (0.555)	0.188* (0.108)	-0.408*** (0.121)	-0.237*** (0.065)	-0.135* (0.081)
First stage F of reverse equation	.	.	.	.	4.782	2.234	1.657	3.749
First stage F of main equation	1.300	0.385	0.658	0.839	222.019	46.742	748.225	315.139
Data imputation	No	Yes	No	Yes	No	Yes	No	Yes
N	133	612	308	612	131	618	308	620
<b>B: log adult female mortality</b>	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
log Public health expenditure	0.403 (0.869)	-0.460 (8.255)	0.178 (0.553)	0.078 (0.268)	0.201* (0.110)	0.483*** (0.159)	0.689*** (0.182)	0.222** (0.086)
First stage F of reverse equation	.	.	.	.	0.958	1.048	0.224	1.256
First stage F of main equation	0.581	0.385	0.392	0.839	153.770	18.868	31.989	64.353
Data imputation	No	Yes	No	Yes	No	Yes	No	Yes
N	119	612	298	612	119	603	298	607
<b>C: log adult male mortality</b>	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
log Public health expenditure	0.188 (0.684)	-0.291 (6.252)	0.346 (0.514)	0.120 (0.229)	-0.298** (0.112)	-0.259*** (0.090)	-0.095** (0.047)	0.043 (0.032)
First stage F of reverse equation	.	.	.	.	0.953	1.631	0.105	2.019
First stage F of main equation	0.581	0.385	0.392	0.839	64.963	35.783	895.420	12969.315
Data imputation	No	Yes	No	Yes	No	Yes	No	Yes
N	119	612	298	612	119	603	298	607

Notes:

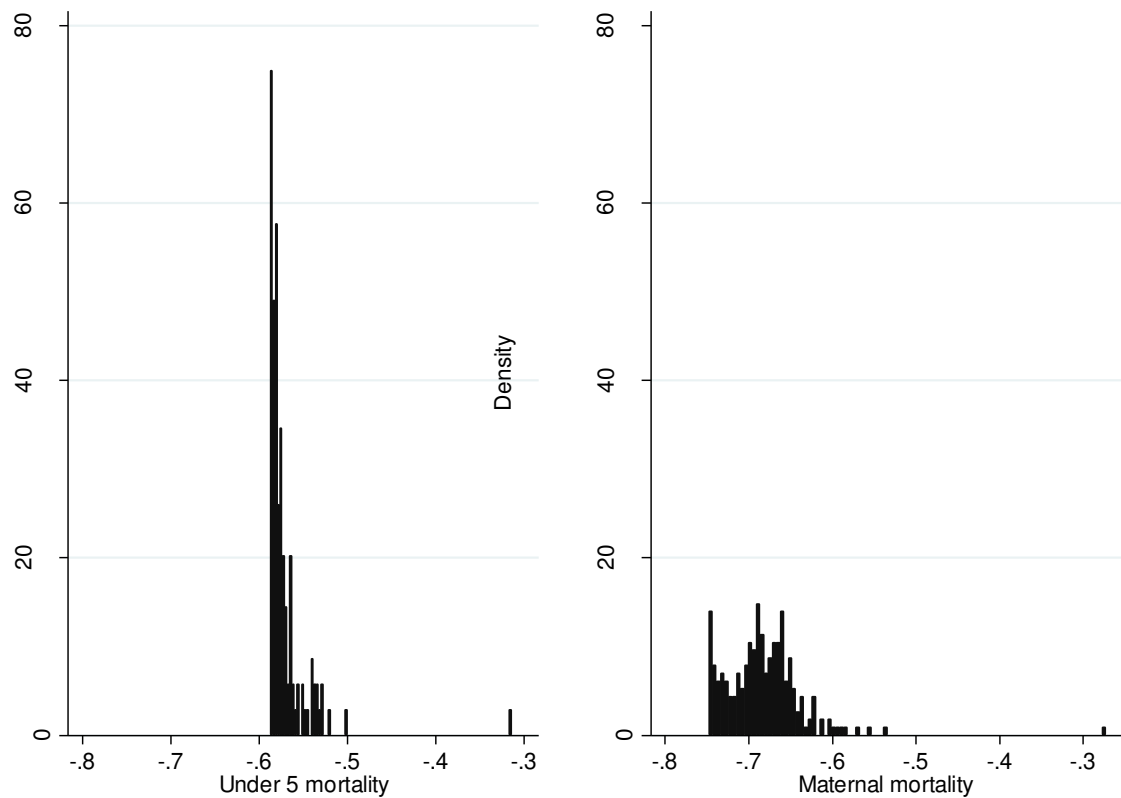
- Model (1) and (2) show the results based on the data from 1995, 2000, 2005 and 2010 (5-year interval data), with and without data imputation, respectively.
- Model (3) and (4) show the results based on the data where five-year average of the variables (1995-1999; 2000-2004; 2005-2009; and 2010-2011) are calculated and used in the regression, with and without data imputation, respectively.

**Table A 9: Traditional IV approach (with streamlined model) in which log GDP per capita is treated as an endogenous variable**

	<b>Fixed effect</b>		<b>Pooled cross section</b>	
<b>A: log under 5 mortality</b>				
	(1)	(2)	(3)	(4)
log Public health expenditure	0.297 (0.519)	0.188 (0.296)	0.660 (0.600)	0.007 (0.222)
log GDP per capita	-0.055 (0.846)	-0.834* (0.439)	-1.262 (0.785)	-0.402** (0.188)
F for log Public health expenditure	1.263	2.573	0.849	1.666
F for log GDP per capita	0.728	2.964	0.860	3.060
Data imputation	No	Yes	No	Yes
N	617	2415	607	2335
<b>B: log adult female mortality</b>				
	(1)	(2)	(3)	(4)
log Public health expenditure	0.267 (0.517)	0.001 (0.212)	0.081 (0.400)	-0.014 (0.212)
log GDP per capita	0.041 (0.952)	-0.177 (0.302)	-0.236 (0.442)	-0.045 (0.174)
F for log Public health expenditure	1.344	2.573	0.857	1.666
F for log GDP per capita	0.605	2.964	0.863	3.060
Data imputation	No	Yes	No	Yes
N	606	2415	597	2335
<b>C: log adult male mortality</b>				
	(1)	(2)	(3)	(4)
log Public health expenditure	0.116 (0.362)	-0.007 (0.166)	0.094 (0.401)	-0.160 (0.183)
log GDP per capita	-0.003 (0.582)	-0.164 (0.253)	-0.410 (0.414)	-0.072 (0.168)
F for log Public health expenditure	1.344	2.573	0.857	1.666
F for log GDP per capita	0.605	2.964	0.863	3.060
Data imputation	No	Yes	No	Yes
N	606	2415	597	2335

Notes: Instrumental variables for log Public health expenditure are the same as the Table 6 (neighbours' military expenditure as % of GDP and neighbours' public health expenditure as % of GDP). Following Bokhari et al. (2007), the instrumental variable for log GDP per capita is the Consumption-Investment ratio of the country (available from Penn World Table, accessed in August 2015).





**Figure A 1: Heterogeneity of the impact of public health expenditure on mortality based on the BGG specification, using year 2000 updated data**

Note: Based on the BGG model (column (4) of Table 4), we estimated the impact of public health expenditure on mortality outcomes, allowing for variations by the level of economic development (proxied by the proportion of paved roads) and by donor funding on health. The histograms are based on 127 countries which are included in the regression analysis.

## Appendix B - Alternative estimation strategies explored

### **B.1 Allowing for lagged impacts of public health expenditure**

A potential reason why we fail (as did some previous studies e.g. Filmer and Pritchett, 1999) to confirm a negative impact of public health expenditure on health could be due to our model estimating the impact of current expenditure on current health outcome. Indeed there may well be lags between healthcare investment and its impact upon population health. To allow for this possibility, we now account for lagged impacts of public health expenditure in the streamlined model. Instead of contemporaneous health expenditure, we now use lagged expenditure (t-1, t-2 and t-5) in the equation as endogenous variables.

### **B.2 Substitution between public and private expenditure**

Another potential reason why we do not find robust enough results to support the expectation that public health expenditures consistently and significantly reduce mortality rates may be that as public health care spending increases, individuals are likely to respond by reducing their previously private expenditures (from out-of-pocket or privately insured sources). As a result the overall resources available to the health care system may not increase as much, compared to a situation in which there would be no such substitution effect, and, hence, unless the marginal productivity of public spending vastly outperforms that of private spending, the overall mortality or health effect associated with a given increase in public health expenditures may be limited or non-existent. While ideally we would want to explicitly model the interrelationship between public and private health expenditures, this is beyond the scope of the present exercise. Instead, in order to circumvent the explicit modelling of the interrelationship it may be instructive to examine the impact of total health expenditure on mortality rates. At least, this would allow us to see whether we are in a position to detect *any* relationship between expenditures and outcomes, and if that was the case, this could be seen as indirect evidence of the importance of a substitution effect.

### **B.3 Allowing for more lagged structure for the impacts of public health expenditure**

We further investigate the potential lagged structure by including lagged public health expenditure (t, t-1, t-2, and t-3) at the same time in the regression models. These models capture the impacts of previous years' expenditure on mortality in the current year, conditional on the impact of the expenditure in the current year. For both Traditional and Bruckner IV approach, the lagged values of the instrumental variables are used as IVs of the lagged public health expenditure, i.e. the IV of the lagged expenditure (t-1) is the lagged IV (t-1).

### **B.4 Further estimation approaches**

In Block D of Appendix Table B3, we present the estimation results based on a dynamic panel approach - Blundell-Bond estimation. In this approach, a 1-year lagged mortality rate is included as an explanatory variable as well as public health expenditure and the same set of covariates (no lag were taken for these variables):

$$\text{Eq. (4): } MO_{jt} = \beta_j + \rho MO_{j,t-1} + \beta_1 EX_{jt} + \mathbf{X}'_{jt}\boldsymbol{\beta} + \varepsilon_{jt}.$$

Taking the first difference for all variables in Eq. (4) eliminates the country level fixed effect  $\beta_j$ . The first-differenced error term  $\varepsilon_{jt} - \varepsilon_{j,t-1}$  is uncorrelated with second or further lags of mortality, health expenditure and the other variables. We use these properties as the moment conditions in the estimation of the model by system Generalised Method of Moments.<sup>30</sup>

<sup>30</sup> Note that, in this dynamic panel data approach, we are only interested in the impact of contemporaneous public health expenditure on contemporaneous mortality. The impact  $dMO_t/dEX_t$  is given by the single coefficient beta.

**Table B 1: Impact of lagged, and total public health expenditure on mortality (streamlined model using instrumental variable approach)**

A: Impact of 1-year lagged health expenditure												
	log under 5 mortality				log adult female mortality				log adult male mortality			
	Traditional IV		Bruckner IV		Traditional IV		Bruckner IV		Traditional IV		Bruckner IV	
	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
log health expenditure (t-1)	-0.262 (0.462)	0.720 (0.766)	0.036 (0.040)	-0.199** (0.093)	-0.408 (0.671)	0.208 (0.318)	1.238* (0.722)	0.019 (0.012)	-0.344 (0.532)	0.131 (0.252)	0.148*** (0.043)	-0.120 (0.075)
First stage F of expenditure (t-1)	0.690	0.712	2804.160	61.301	0.458	0.712	3.871	10690547.8	0.458	0.712	80.659	31.121
Imputation	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes
N	661	2447	382	2476	642	2447	369	2451	642	2447	369	2451
B: Impact of 2-year lagged health expenditure												
	log under 5 mortality				log adult female mortality				log adult male mortality			
	Traditional IV		Bruckner IV		Traditional IV		Bruckner IV		Traditional IV		Bruckner IV	
	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
log health expenditure (t-2)	-0.218 (0.252)	0.669 (0.741)	0.061 (0.046)	-0.177** (0.083)	-0.118 (0.246)	0.081 (0.252)	1.664 (1.479)	0.015 (0.012)	-0.132 (0.214)	0.053 (0.217)	0.155*** (0.051)	-0.094 (0.066)
First stage F of expenditure (t-2)	1.878	0.746	1516.7	71.363	1.426	0.746	1.382	9753700.8	1.426	0.746	54.508	32.963
Imputation	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes
N	603	2295	413	2321	585	2295	400	2308	585	2295	400	2308
C: Impact of 5-year lagged health expenditure												
	log under 5 mortality				log adult female mortality				log adult male mortality			
	Traditional IV		Bruckner IV		Traditional IV		Bruckner IV		Traditional IV		Bruckner IV	
	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
log health expenditure (t-5)	-0.036 (0.116)	-0.281 (0.465)	-0.033 (0.045)	-0.113** (0.056)	-0.157 (0.109)	-0.308 (0.361)	1.299 (1.071)	0.011 (0.010)	-0.014 (0.074)	-0.394 (0.393)	0.080 (0.054)	-0.036 (0.039)
First stage F of expenditure (t-5)	2.892	0.921	889.299	88.489	2.991	0.921	1.728	8346576	2.991	0.921	28.507	38.357
Imputation	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes
N	556	1832	226	1856	538	1832	214	1844	538	1832	214	1844
D: Impact of total health expenditure												
	log under 5 mortality				log adult female mortality				log adult male mortality			
	Traditional IV		Bruckner IV		Traditional IV		Bruckner IV		Traditional IV		Bruckner IV	
	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
log total health expenditure	-0.197 (1.174)	0.606 (2.009)	-0.093* (0.048)	-0.299*** (0.045)	-0.404 (0.864)	-0.486 (0.894)	0.018 (0.037)	0.228*** (0.052)	-0.232 (0.624)	-0.219 (0.774)	-0.331*** (0.083)	0.021 (0.031)
First stage F of reverse equation	.	.	1.262	3.696	.	.	0.096	4.461	.	.	1.293	3.696
First stage F of main equation	0.393	0.244	36756.8	1776.2	0.491	0.244	373761.6	635.921	0.491	0.244	122.514	129224.7
Imputation	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes
N	661	2601	666	2631	642	2601	647	2590	642	2601	647	2590

Notes: In Block A, B and C, the first stage F of the reverse causality model in the Bruckner IV approach is not presented in the table. Following Moreno-Serra and Smith (2015), once the residual from the reverse causality model is estimated (see Eq.(3) in Method section), its lag is calculated and used as instrumental variable in the main regression model.

**Table B 2: Impact of present and lagged health expenditure on mortality (streamlined model using instrumental variable approach)**

A: Impact of contemporaneous and lagged (1 year only) health expenditure												
	log under 5 mortality				log adult female mortality				log adult male mortality			
	Traditional IV		Bruckner IV		Traditional IV		Bruckner IV		Traditional IV		Bruckner IV	
	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
log health expenditure (t)	0.267 (0.487)	0.610 (0.592)	0.064 (0.042)	-0.153*** (0.051)	0.390 (0.721)	0.300 (0.223)	1.720* (1.021)	0.017** (0.008)	0.490 (0.709)	0.253 (0.180)	0.304*** (0.096)	-0.104*** (0.035)
log health expenditure (t-1)	-0.367 (0.287)	0.042 (0.514)	0.008 (0.035)	-0.088 (0.067)	-0.400 (0.244)	-0.085 (0.245)	0.648 (0.714)	0.007 (0.011)	-0.393 (0.238)	-0.096 (0.200)	0.010 (0.046)	-0.048 (0.057)
First stage F of expenditure (t)	0.576	1.712	7776.995	512.554	0.290	1.712	5.622	2.916e+08	0.290	1.712	58.792	1156.531
First stage F of expenditure (t-1)	2.225	1.797	41340.818	450.828	2.054	1.797	9.018	2.197e+08	2.054	1.797	79.947	750.556
Imputation	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes
N	661	2447	382	2476	642	2447	369	2434	642	2447	369	2434
B: Impact of contemporaneous and lagged (1 and 2 years) health expenditure												
	log under 5 mortality				log adult female mortality				log adult male mortality			
	Traditional IV		Bruckner IV		Traditional IV		Bruckner IV		Traditional IV		Bruckner IV	
	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
log health expenditure (t)	0.376 (0.488)	0.322 (0.341)	0.096** (0.045)	-0.166*** (0.047)	0.459 (0.734)	0.019 (0.136)	2.795 (4.173)	0.010 (0.009)	0.378 (0.665)	0.050 (0.123)	0.278*** (0.097)	-0.113*** (0.034)
log health expenditure (t-1)	-0.075 (0.397)	0.193 (0.285)	-0.022 (0.027)	-0.009 (0.026)	-0.424 (0.555)	0.107 (0.112)	1.708 (4.342)	0.010** (0.004)	-0.445 (0.520)	0.066 (0.095)	0.041 (0.058)	-0.008 (0.014)
log health expenditure (t-2)	-0.357 (0.240)	-0.237 (0.395)	-0.031 (0.039)	-0.088 (0.057)	-0.060 (0.293)	-0.249 (0.161)	1.839 (4.033)	0.003 (0.010)	-0.058 (0.269)	-0.218 (0.141)	-0.029 (0.055)	-0.036 (0.049)
First stage F of expenditure (t)	0.628	2.152	10571.0	2086.008	0.539	2.152	0.866	3.522e+08	0.539	2.152	52.780	1029.291
First stage F of expenditure (t-1)	0.987	1.736	43483.6	1592.700	0.801	1.736	0.421	6.542e+08	0.801	1.736	49.621	938.015
First stage F of expenditure (t-2)	2.423	1.835	29486.1	2415.063	2.243	1.835	0.814	4.166e+08	2.243	1.835	75.358	814.302
Imputation	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes
N	603	2295	304	2321	585	2295	292	2280	585	2295	292	2280
C: Impact of contemporaneous and lagged (1, 2 and 3 years) health expenditure												
	log under 5 mortality				log adult female mortality				log adult male mortality			
	Traditional IV		Bruckner IV		Traditional IV		Bruckner IV		Traditional IV		Bruckner IV	
	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
log health expenditure (t)	0.318 (0.419)	-0.030 (0.193)	0.148*** (0.038)	-0.076** (0.030)	0.420 (0.602)	-0.073 (0.116)	1.006** (0.476)	-0.073 (0.116)	0.260 (0.512)	-0.065 (0.103)	0.285*** (0.089)	-0.065 (0.103)
log health expenditure (t-1)	-0.143 (0.321)	0.045 (0.165)	-0.003 (0.027)	-0.023 (0.016)	-0.341 (0.390)	-0.017 (0.098)	0.138 (0.415)	-0.017 (0.098)	-0.347 (0.357)	-0.014 (0.086)	-0.004 (0.048)	-0.014 (0.086)
log health expenditure (t-2)	-0.263 (0.226)	0.126 (0.205)	0.007 (0.023)	-0.013 (0.012)	-0.189 (0.213)	0.118 (0.105)	0.463 (0.577)	0.118 (0.105)	-0.178 (0.165)	0.075 (0.093)	-0.001 (0.052)	0.075 (0.093)
log health expenditure (t-3)	0.034 (0.182)	0.105 (0.243)	-0.029 (0.036)	-0.053 (0.040)	0.045 (0.216)	-0.254* (0.150)	0.441 (0.737)	-0.254* (0.150)	0.078 (0.181)	-0.219* (0.131)	0.022 (0.050)	-0.219* (0.131)
First stage F of expenditure (t)	0.733	3.473	10578.6	34655.090	0.691	3.473	4.380	3.473	0.691	3.473	68.129	3.473
First stage F of expenditure (t-1)	2.042	2.555	125656.0	107866.910	1.757	2.555	3.524	2.555	1.757	2.555	70.385	2.555
First stage F of expenditure (t-2)	1.782	1.762	40257.7	829780.259	1.710	1.762	3.648	1.762	1.710	1.762	30.885	1.762
First stage F of expenditure (t-3)	1.284	1.820	33858.4	230538.810	1.361	1.820	2.131	1.820	1.361	1.820	73.709	1.820
Imputation	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes
N	603	2142	226	2138	585		226	2142	585	2142	226	2142

**Table B 3: Alternative estimation approaches (fixed effect plus lagged expenditure; dynamic panel specification)**

<b>A: Impact of contemporaneous health expenditure: Fixed effect model</b>						
	<b>log under 5 mortality</b>		<b>log adult female mortality</b>		<b>log adult male mortality</b>	
	(1)	(2)	(1)	(2)	(1)	(2)
log health expenditure	-0.026 (0.035)	-0.005 (0.020)	-0.026 (0.029)	0.025** (0.011)	-0.021 (0.026)	0.042** (0.018)
Imputation	No	Yes	No	Yes	No	Yes
N	688	2635	669	2635	669	2635
<b>B: Impact of 1-year lagged health expenditure: Fixed effect model</b>						
	<b>log under 5 mortality</b>		<b>log adult female mortality</b>		<b>log adult male mortality</b>	
	(1)	(2)	(1)	(2)	(1)	(2)
log health expenditure (t-1)	-0.044 (0.029)	-0.015 (0.021)	-0.022 (0.025)	0.020* (0.012)	-0.015 (0.022)	0.038* (0.020)
Imputation	No	Yes	No	Yes	No	Yes
N	687	2479	668	2479	668	2479
<b>C: Impact of 2-year lagged health expenditure: Fixed effect model</b>						
	<b>log under 5 mortality</b>		<b>log adult female mortality</b>		<b>log adult male mortality</b>	
	(1)	(2)	(1)	(2)	(1)	(2)
log health expenditure (t-2)	-0.052* (0.030)	-0.024 (0.023)	-0.028 (0.026)	0.017 (0.011)	-0.025 (0.022)	0.035* (0.020)
Imputation	No	Yes	No	Yes	No	Yes
N	636	2325	618	2325	618	2325
<b>D: Impact of contemporaneous health expenditure: Blundell-Bond dynamic panel estimation</b>						
	<b>log under 5 mortality</b>		<b>log adult female mortality</b>		<b>log adult male mortality</b>	
	(1)	(2)	(1)	(2)	(1)	(2)
lagged mortality (t-1)	1.058*** (0.166)	1.128*** (0.197)	1.063*** (0.046)	1.061*** (0.044)	1.058*** (0.129)	1.033*** (0.034)
log health expenditure	-0.011 (0.331)	-0.021 (0.049)	-0.011 (0.009)	-0.019 (0.026)	0.065 (0.185)	-0.024 (0.031)
Imputation	No	Yes	No	Yes	No	Yes
P value of Hansen test	0.791	0.002	0.478	0.001	0.361	0.008
P value of AR(1) test	0.808	0.269	0.003	0.006	0.038	0.006
P value of AR(2) test	0.709	0.701	0.272	0.229	0.348	0.204
Number of instruments	28	31	28	31	28	31
N	688	2480	669	2480	677	2480

## Appendix C – Further descriptive statistics

**Table C 1: Descriptive statistics of BGG data (original data and updated data)**

	Original data (2000)			Updated data (2000)		
	Mean	SD	N	Mean	SD	N
Under 5 mortality	73.49	68.91	127	65.83	59.82	127
Maternal mortality	345.39	425.07	127	290.93	364.00	125
GDP per capita†	6962.60	7987.95	127	10227.33	11868.58	125
Public health expenditure‡	311.21	509.70	127	433.55	843.80	126
Neighbours' military expenditure per capita	161.04	183.22	127	162.13	263.19	127
World Bank CPI on Social inclusion and equity	3.63	0.76	127	.	.	.
World Bank CPI on Economic management	3.96	1.05	127	.	.	.
Investment-GDP ratio	14.87	8.71	127	14.87	8.71	127
Donor funding on basic health per capita	2.96	6.35	127	.	.	.
Nonliterate rate	21.22	22.15	127	23.20	20.52	33
Paved road rate	31.14	66.63	127	40.58	30.65	81
Sanitation rate	73.98	26.67	127	62.74	32.02	125

**Notes:**

\* In this column the analysis include as many countries as possible (max available number of countries is 238) from the updated data sources.

† In the original data, GDP per capita using international dollars as of 2000 is used. In the updated data, GDP per capita using constant US dollars 2011 (PPP adjusted) is used.

‡ In the original data, government health expenditure per capita (international dollars as of 2000) is used. In the updated data, government health expenditure per capita in 2005 constant dollars is used.

**Table C 2: Descriptive statistics of MSS data (original data and updated data)**

	Original data (1995-2008)			Updated data (1995-2008)		
	Mean	SD	N (153 countries)	Mean	SD	N (153 countries)
Under 5 mortality	45.68	48.87	1397	45.68	48.87	1397
Adult female mortality	155.85	114.87	1225	161.41	122.46	1397
Adult male mortality	226.39	116.92	1225	230.83	118.42	1397
public health expenditure (1/100)†	5.99	8.43	1397	6.58	9.80	1397
Privately pooled health expenditure (1/100)	0.59	2.10	1397	2.60	13.42	1397
Out-of-pocket health expenditure (1/100)	1.88	2.04	1397	0.72	2.39	1264
Immunization coverage (1/10)	8.61	1.42	1397	8.63	1.44	1397
GDP per capita (1/100)‡	121.15	131.67	1397	168.17	194.49	1374
Primary education enrollment rate (1/10)	8.61	1.59	1397	8.81	1.57	1235
Proportion of population under 14 (1/10)	3.07	1.05	1397	3.08	1.06	1397
Proportion of population over 65 (1/10)	0.75	0.52	1397	0.76	0.52	1397
CO2 emission per capita	5.16	6.51	1397	5.09	6.52	1397
Death by conflict	1.45	25.76	1397	1.29	23.88	1397

**Notes:**

\* In this column the analysis include as many countries as possible (max available number of countries is 229) from the updated data sources.

† In the original data, government health expenditure per capita (international dollars as of 2005) is used. In the updated data, government health expenditure per capita in 2005 constant dollars is used.

‡ In the original data, GDP per capita using international dollars as of 2005 is used. In the updated data, GDP per capita using constant US dollars 2011 (PPP adjusted) is used.

**Table C 3: Descriptive statistics of the updated BGG data 2010**

	Original data (2000)			Updated data (2010)					
	Mean	SD	N	Mean	SD	N	# missing	max N	Missing rate
Under 5 mortality	73.49	68.91	127	39.36	41.44	192	51	243	20.99%
Maternal mortality	345.39	425.07	127	182.55	242.17	183	60	243	24.69%
GDP per capita†	6962.60	7987.95	127	17010.99	19625.66	189	54	243	22.22%
Public health expenditure‡	311.21	509.70	127	799.50	1792.02	187	56	243	23.05%
Neighbours' military expenditure per capita	161.04	183.22	127	341.46	529.26	222	21	243	8.64%
World Bank CPI on Social inclusion and equity	3.63	0.76	127	.	.	.	.	.	100.00%
World Bank CPI on Economic management	3.96	1.05	127	.	.	.	.	.	100.00%
Investment-GDP ratio	14.87	8.71	127	24.53	11.50	189	54	243	22.22%
Donor funding on basic health per capita*	2.96	6.35	127	7.92	13.37	192	51	243	20.99%
Nonliterate rate	21.22	22.15	127	17.05	18.72	43	200	243	82.30%
Paved road rate	31.14	66.63	127	62.54	30.97	79	164	243	67.49%
Sanitation rate	73.98	26.67	127	72.27	29.97	186	57	243	23.46%

Notes:

\*While in the original BGG data, per capita donor funding for health promotion from the Development Assistance Committee (DAC) of the Organization for Economic Co-operation and Development (OECD) in year 1998 is used. In the updated 2010 data, we instead use the data on per capita amount of Development Assistance for Health (DAH), available at the Institute of Health Metrics and Evaluation database.

†In the original data, GDP per capita using international dollars as of 2000 is used. In the updated data, GDP per capita using constant US dollars 2011 (PPP adjusted) is used.

‡In the original data, government health expenditure per capita (international dollars as of 2000) is used. In the updated data, government health expenditure per capita in 2005 constant dollars is used.

## Appendix D - Review of related studies using cross-country data

**Table D 1: Review of related studies using cross-country data**

Author	Publication year	Region	Data source	Data years	Outcome	Expenditure	Main result (Not necessarily significant)	Model	IV	Covariates
Afridi & Ventelou	2013	All, 113 countries	IHME, WHO	1995-2006	Adult mortality	Aid (public and private); Govt health expenditure	Aid reduces adult mortality	Dynamic panel system GMM	Lagged aid	per capita health aid by government; per capita health aid by private channel; per capita non-health aid; per capita government health expenditure; per capita private health expenditure; per capita GDP
Akinci et al	2014	MENA, 19 countries	WHO, WDI	1990-2010	Infant mortality; U-5 mortality; maternal mortality	Govt expenditure & govt expenditure as % of THE; Private expenditure & OOP expenditure as % of THE (separately)	Govt and private expenditure improve outcome variables	Hausman-Taylor panel model	Random effect variable	govt expenditure on health as percentage of total exp on health; physicians density; hospital beds; population with access to safe drinking water; birth attended by skilled health personnel; adult literacy rate
Anyanwu & Erhijakpor	2009	Africa, 47 countries	WHO, WDI, African Development Bank's database	1999-2004	U-5 mortality rate; infant mortality rate	Total health expenditure; public health expenditure	Health expenditure reduces infant mortality and U-5 mortality	2SLS	Consumption-investment rate (for income); Military expenditure of neighbouring countries and membership of the Franc zone (for expenditure)	Ethnolinguistic fractionalization; female literacy; physicians per 100,000 population; urban population; per capita GDP (HIV prevalence, not included due to data limitation)
Bokhari et al	2007	All, 127 countries	WB's in-house data, WDI, Millennium Indicators database, World Health Report, Human Development Report, CIA fact book, UN websites, Penn World Tables	2000	U-5 mortality; maternal mortality (MDG outcomes)	Public expenditure; donor funding	Health expenditure reduces U5MR and MMR	GMM-H2SL	Military expenditure of neighbouring countries and its interactions (for govt health expenditure); WB annual assessments on the quality of policies and institutions	GDP per capita (endogenous); % population aged 15 or above not literate; paved roads per unit area; % population with access to improved sanitation; donor funding per capita for basic health



**Table D 1: Review of related studies using cross-country data (continued)**

Author	Publication year	Region	Data source	Data years	Outcome	Expenditure	Main result (N.B. impacts are not always statistically or economically significant)	Model	IV	Covariates
Farag et al	2013	LMIC, 133 countries	NHA of WHO; UNICEF; World Resources Institute; World Databank; WB	1995, 2000, 2005, 2006	U-5 mortality; infant mortality	Gvt health spending	Health expenditure reduces U5MR and Infant mortality	Fixed effect (no IV)	NA	per capita GDP; total health spending; govt health spending; donor health spending; fertility rate; urban population; female labor; school enrollment; improved water source; improved sanitation facilities; share of women employed in the nonagriculture sector; TB detection rate; female literacy; physicians per 100,000
Filmer & Pritchett	1999	All, 119 countries	UNICEF; ministries of Health data; WB	1990	U-5 mortality; infant mortality	Public expenditure on health	Public health expenditure has small and insignificant impacts	2SLS	Average public sector health spending as a share of GDP; average defense spending as a share of GDP of neighbouring countries	GDP per capita; public exp on health (share of GDP); female education; income inequality; predominantly muslim; ethno-linguistic fractionalisation; percentage urban; tropical country; access to safe water
Gani	2009	Pacific Island, 7 countries	WHO, WB, Asian Development Bank	1990, 2002	U-5 mortality; infant mortality; crude death rate	Total health expenditure per capita	Health expenditure reduces U5MR and Infant mortality	Fixed effect controlling for AR(1), no IV	NA	per capita income; immunization; urbanisation; calorie intake
Hu & Mendoza	2013	All, 136 countries	Globalization and Health Nexus Database; WDI; International Country Risk Guide	1960-2005	U-5 mortality; infant mortality	Public spending on health	Public spending reduces child mortality	2SLS	Legal origin of country (UK law, French law, socialist law, German law, Scandinavian law); democracy (democratic accountability index by International Country Risk Guide)	Volatility; Gini coefficient; female literacy rate; public spending on health (% GDP); quality of bureaucracy; control of corruption

**Table D 1: Review of related studies using cross-country data (continued)**

Author	Publication year	Region	Data source	Data years	Outcome	Expenditure	Main result (N.B. impacts are not always statistically or economically significant)	Model	IV	Covariates
Moreno-Serra & Smith	2015	All, 153 countries	WHO, WB, IHME	1995-2008	U-5 mortality; adult mortality (female and male)	Public expenditure; OOP expenditure; private insurance	Health expenditure reduces mortality	2SLS	CO2 emission and battle related deaths (*reverse causality estimation)	GDP per capita; primary education enrolment rate; population aged under 14; population aged over 65; CO2 emission & conflict deaths (IVs)
Rajkumar & Swaroop	2008	All, 91 countries	WDI, and other sources (see Appendix A)	1990, 1997, 2003	U-5 mortality	Public health expenditure (ln of share of GDP)	Public health spending reduces mortality only for countries with good governance	2SLS	Legal origin of country	GDP per capita; index of corruption; quality of bureaucracy; female education; income inequality; predominantly muslim; ethnolinguistic fractionalisation; access to safe water; degree of urbanization; percentage of population under 5; distance from the Equator
Wagstaff & Claeson	2004	All	WB, and other sources (see Table A.1 pp 171)	1990s	U-5 mortality	Public health expenditure	Govt health spending modestly improves health for well governed countries	2SLS	Average defense and health spending on neighbouring countries; average value of an index of "voice" among neighbours	Not known